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AN ANALYSIS OF ELECTROENCEPHALOGRAMS

Edwin Richard Wicklander

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THESIS

AN ANALYSIS OF ELECTROENCEPHALOGRAMS

by

Edwin Richard Wicklander

March 1975

Thesis Advisor: G. Marmont

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Block #20 continued

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An Analysis of Electroencephalograms

by

Edwin Richard Wicklander
Lieutenant, United States Navy
B.S.E.E., Purdue University, 1968

Submitted in partial fullfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1975

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I. INTRODUCTION

A. BIOENGINEERING

Bioengineering deals with the application of science and technology to problems of biology and medicine. Students who take the master's program bioengineering sequence are afforded the opportunity to explore this fascinating field, and to apply their electronics education to problems directly related to man. One interesting area of bioengineering involves the study of the human nervous system, especially the brain. It is a particularly apt field of endeavor when one considers that the nervous system of man is a nonlinear, stochastic, electrochemical device. The brain comprises the largest part of the nervous system.

Precisely how does one think? How does one remember? What makes one person more intelligent than another? Can any form of feedback be employed to aid learning? We don't know answers to these questions yet, but state-of-the-art advances in electronics and computers are hopefully at last providing us with the tools to find out. The author's thesis represents a part of a research project which addresses the above questions.

B. THE RESEARCH PROJECT

The research project is an ongoing project under the direction and guidance of Professor George Marmont. It involves the detection and analysis of electroencephalograms (EEG's) from human subjects while performing mental tasks.

The objectives of the project are:

1. To obtain new insight about how the brain functions.

2. To determine what recognizable EEG patterns exist while the brain is involved in mental tasks.

3. To investigate ways of feeding back a portion of the EEG to enhance successful completion of a mental task.

4. To explore methods of biofeedback which would aid in pattern recognition.

Since its inception in 1971, five students have been involved with and submitted theses regarding this project. The project is expected to encompass several years. It is being sponsored by NAVELEX.

C. THE AUTHOR'S CONTRIBUTION

The author has participated as a subject in the research project. He has also assisted in the collection, recording, and study of EEG data. His main contribution is this thesis.

II. BACKGROUND

A. THE ELECTROENCEPHALOGRAM

1. Definition

The electroencephalogram (EEG) is a record of the minute changes in the electric potential associated with the activity of the cerebral cortex, as detected by electrodes contacting the surface of the scalp. The magnitude of the scalp EEG is a function of location, frequency, and brain activity.

Traditional EEG analysis has been performed using strip chart recorders and a filter bandwidth of zero to between 30 and 50 Hz. In the present project wideband amplifiers (zero to 1000 Hz) have been used, as well as ideal digital filtering techniques to study various frequency bands.

2. Tegules

An early team research discovery made by Professor Marmont and LT Stephen Dollar was that the raw EEG is really the summation of discrete frequency sinusoids. The sinusoids have spindle shaped envelopes of varying duration. They have been given the name tegules. It is felt that tegules represent a unit signature of cortical activity, and are the result of cortical activity in definable regions of the cortex [Ref. 1].

The author would like to stress at this point that tegules are *not* responses to an impulse *or* short, noise-like

or impulse-like disturbances. This can be clearly seen by observing EEG's where it is seen that:

a. Tegules are not time coincident on one channel from one filter band to another;

b. Tegules are usually offset from channel to channel in the same frequency band;

c. They are detected clearly in the overall EEG as sinusoid responses so that the overall EEG can be considered a summation of the tegules occurring at different frequencies.

3. The Nerve Cell

The sources of the electric potentials are, of course, the estimated 10 billion nerve cells which comprise the outer 1.4 to 4 mm layer of the cortex. Figure 2-1 shows a simplified diagram of a cortical pyramidal neuron. The principal parts of interest are the cell body (soma), axon hillock, axon, dendrites, synaptic clefts, and synaptic knobs (boutons).

It is known that an electric potential exists across the cell membrane of virtually all body cells. By the use of microelectrodes inserted just inside and outside the membrane, this potential has been observed to be approximately -85 milli-volts. Nerve cells have the additional property of being "excitable," i.e., they are capable of transmitting electrochemical impulses along their membranes. This is due to the observed fact that anything which will suddenly increase the cell's permeability to sodium will cause a rapid change in the membrane's electric potential which will last about one millisec, then return to it's resting value. This sequence

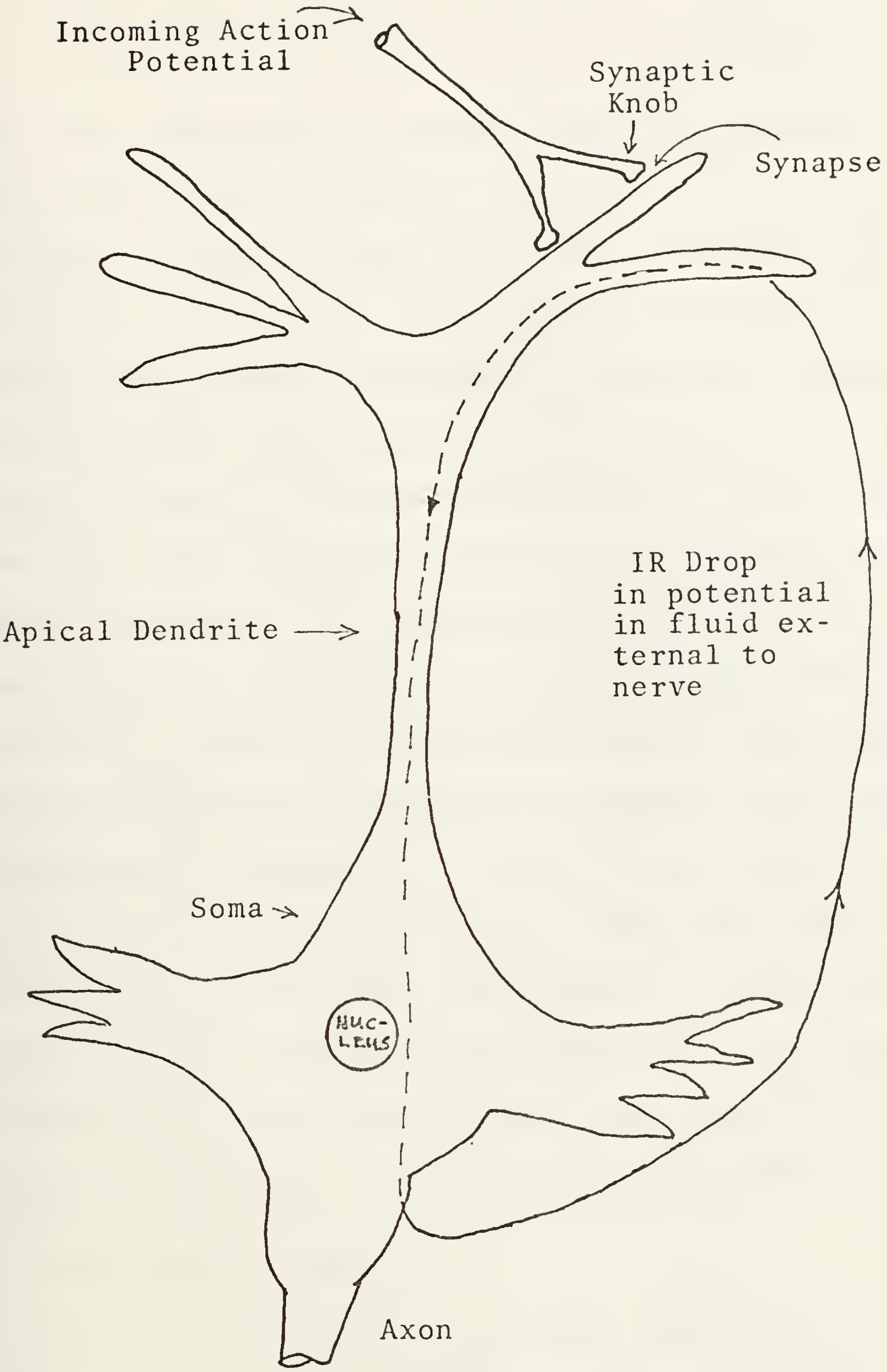

Incoming Action Potential
Synaptic Knob
Synapse
IR Drop in potential in fluid external to nerve
Apical Dendrite
Soma
NUC-LEUS
Axon

Figure 2-1. Simplified diagram of a pyramidal cell in the cortex.

of events generates what is called an "action potential." It is this potential which is then propagated down the axon. The axon terminates at synaptic knobs or boutons, which are in close physical proximity (approx. 200 Å) to another nerve cell body (soma) or nerve cell body outgrowths (dendrites). This action potential, upon reaching the synaptic knob, causes small packets (vesicles) of chemical substance to be released which depending on the chemical substance type, raises or lowers the membrane potential of the receiving cell. Generally just one such synapse is insufficient to cause an action potential to be generated in the receiving nerve cell. However, many such synapses acting in concert will cause a noticeable change in the membrane system which when summed with similar events occurring in adjacent nerve cells, is sufficient to generate an IR drop in the interstitial fluid which is picked up on the scalp. Therefore each nerve cell can produce two different wave forms: a slowly varying membrane potential and an action potential. It is the summation of these potentials from all the cells beneath the electrodes which produces the electroencephalogram [Refs. 2, 8, 9].

B. THE CEREBRAL CORTEX

The cerebral cortex is the outer gray layer of the brain. The functional part of the cerebral cortex is the outer 1.5 to 4 mm portion. Due to the convolutions of the surface, this represents an area of about 2300 sq cm, containing some 10 billion nerve cells. Figure 2-2 shows a representative cortex structure. It is the cortex that is responsible for man's

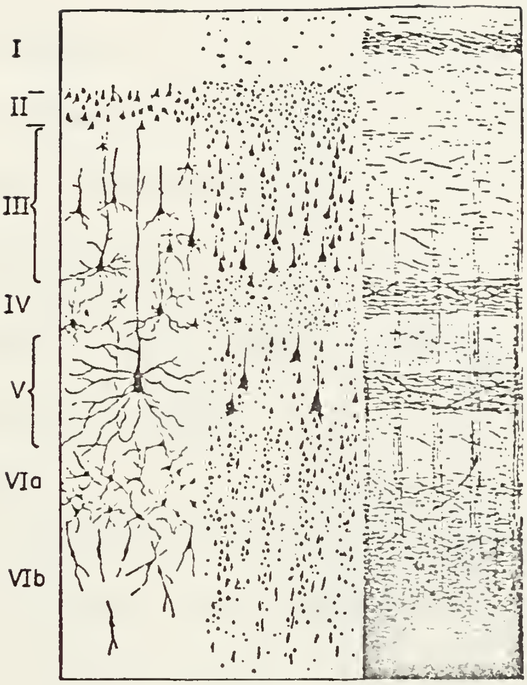


Figure 2-2. Structure of the cerebral crotex.

intellect and reasoning ability. It is known that all areas of the cortex have connections to and from subcortical subcenters of the brain. These subcortical centers act as relay points for information to and from the cortex. Different cortical regions are also known to communicate with each other via these subcenters [Ref. 3].

C. THE LABORATORY SET-UP

Figure 2-3 shows a block diagram of the laboratory set-up used for the research project.

1. Electrodes

Beckman miniature 2 mm diameter silver electrodes were used. The electrodes are placed and attached to the head by means of a special helmet arrangement designed by Professor Marmont and ENS Russ McWey. The use of the helmet allows fast, precise placement of electrodes from subject to subject. It also provides a more consistent EEG measurement by eliminating the need for a conductive paste between the electrode and the scalp [Ref. 4]. The helmet has proved far superior to the previous method which used electrode paste to provide intimate contact between the electrode and the scalp and used an elastic headband to hold the electrode in place. The electrode paste tended to dry quickly, which caused a resistance change between electrode and scalp. This in turn altered the EEG measurement. The elastic band holding arrangement had a nasty habit of slipping at the wrong time [Ref. 1].

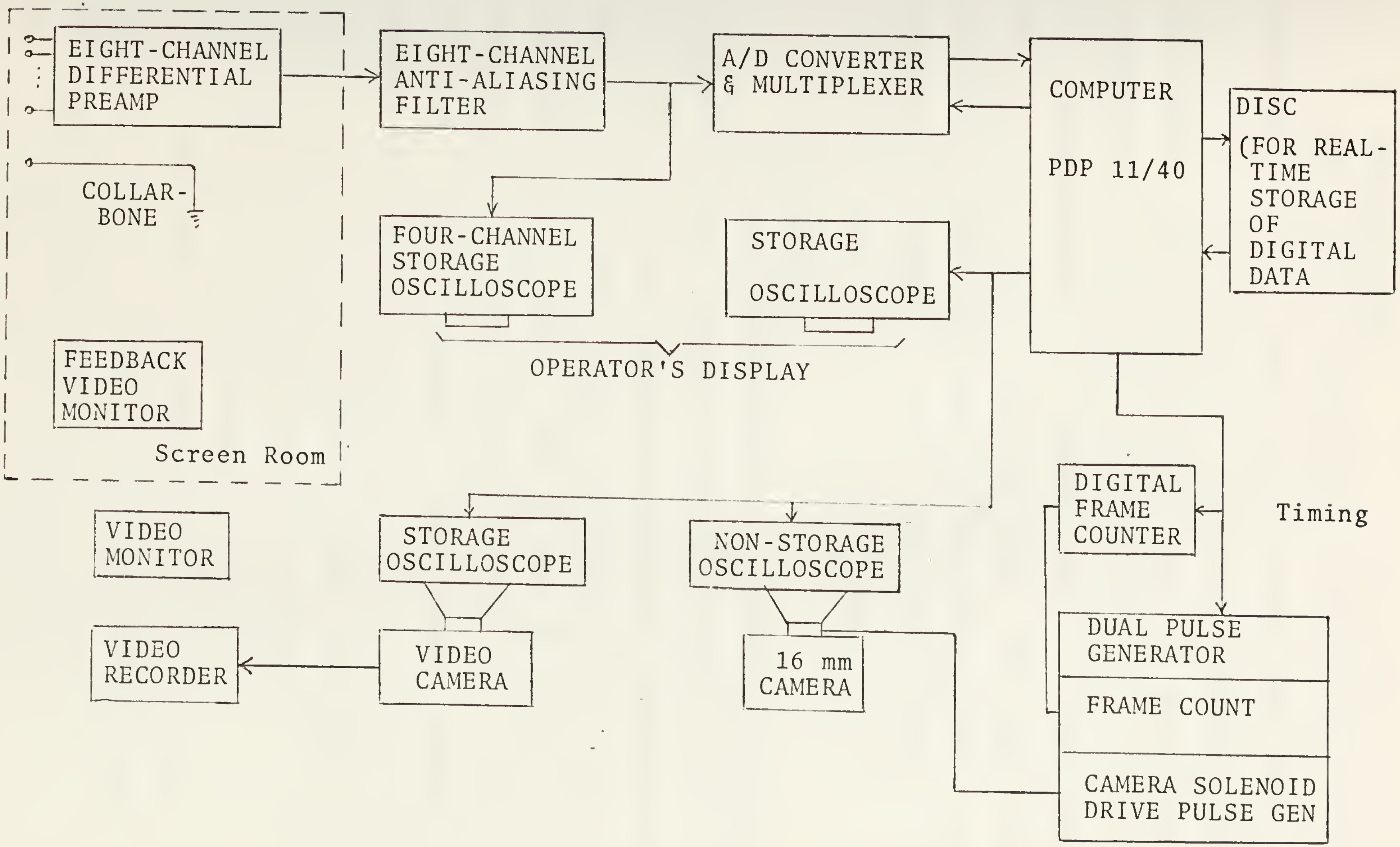


Figure 2-3. Block diagram cf experimental set-up.

2. Recording Mode

The circuit arrangement by which the electrodes are connected to their respective differential amplifiers is called the recording mode. The current recording mode is the average electrode mode (Fig. 2-4). In the average electrode mode one input lead of all amplifiers is connected to the reference point of a summing network in which equal (80K) resistors are taken to each electrode. This mode was chosen because it allows observance of the EEG generated directly under each electrode. At the same time it ignores that part of the EEG common to all the electrodes.

3. Interference

Electrical signals due to the muscular activity (electromyograms) and due to the heart (electrocardiograms) are often of several orders of magnitude greater than the EEG. To successfully record and analyze EEG's, one must eliminate these signals. This is done in the Bio Lab by connecting an electrode from system ground to an area of skin directly over the collarbone of the subject. However, this doesn't eliminate electromyograms due to muscular activity in the neck and head. To eliminate these, the subject is placed in a reclining chair equipped with a head rest so that he may relax his head and neck as much as possible.

Environmental signals detected on the scalp, especially 60 Hz, are also orders of magnitude greater than the EEG. The unwanted signals are uniform over the entire scalp surface. To eliminate these, the electrodes are fed into differential amplifiers having a Common Mode Rejection Ratio of

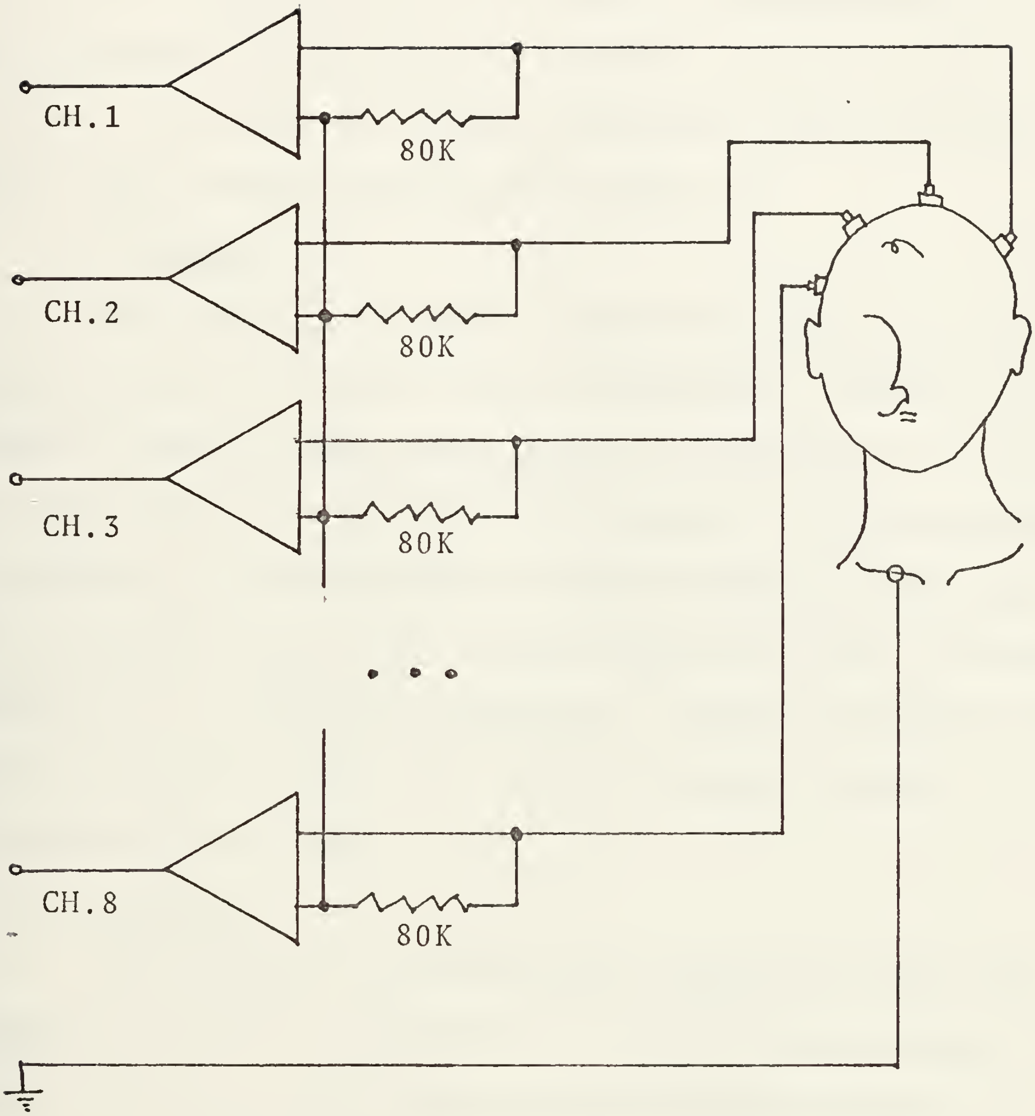


Figure 2-4. Averaging circuit used for averaging electrode references.

greater than 90 db. These amplifiers also provide the amplification necessary to feed into the analog-to-digital converter.

Other possible outside interference such as RF signals being picked up and rectified by the amplifier circuits was eliminated by placing the subject in an 8' by 10' room entirely enclosed with copper screening, and by careful power supply design and filtering [Ref. 5].

4. Computer

The PDP-11/40 (Digital Equipment Corporation) computer was used to process the EEG signals. The use of this computer enables real-time analysis of the EEG. It can present the results in either the frequency or the time domain. In addition, it enables one to employ digital filtering. Data storage is provided via two disc units with a storage capacity of 1.2 million words/disc. Program storage is provided via two dec-tape units with a storage capacity of 148,000 words per tape.

5. Cameras

When desired, the processed information from the computer can also be displayed on a non-storage remote oscilloscope where it can be photographed frame-by-frame via a 16 mm camera. Another remote storage oscilloscope can be monitored by a video camera. The output from the camera can be taped or fed back to a monitor in the screen room.

6. Plotter

Digital data stored on the disc can be converted to an analog form and plotted on a Hewlett Packard *point* plotter.

The plotter enables one to make either single graphs or strip chart recordings.

III. OBJECTIVES

A. OVERALL OBJECTIVE

The overall objective of this thesis is to determine if certain adjacent cortical areas show significantly increased correlation of activity during mental processing.

1. Parallel Processor

The brain has been thought of as a body's computer. It is, of course, a natural comparison to make. One must be aware, however, of the differences in how the brain functions and how a computer functions [Ref. 10].

The modern computer is a serial processor. It can go from step A to step B, C,...n and give an output. This serial process enables the computer to process a complicated mathematical problem and obtain a mathematical solution much faster than a man would.

One reason for the special limitation on man is the delay in transmission from one neuron to another across the synaptic cleft. This process as explained in Section IIB takes on the order of 0.5 milliseconds or more.

The brain, however, can do many things the most expensive computer cannot do. Its memory capacity far exceeds that of even the largest computer.

The brain far excels in its ability to discriminate and recognize patterns. One's ability to recognize a person from the sound of one word or to immediately identify one person out of a large group by recognizing a characteristic

stance or movement are but two examples of what the brain can do and the computer cannot.

Since it routinely performs such functions and since it cannot match the computer's speed, one must surmise that the brain acts as a vast parallel processor. If it is, one would expect to find a correlation between the EEG's taken from selected areas of the scalp.

2. Distinctive Frequency Signature

Discovery of tegules led to the question, "Will mental processing show a distinctive frequency signature?" Professor Marmont devised a very complicated program which he called HISCAN, to find out. The HISCAN program processes selectable blocks of data and performs a scanning histogram of the data from zero to 207 Hertz. Preliminary runs do indicate the presence of preferred frequency bands in the 50-207 Hertz range while the subject is performing mental tasks.

B. FEEDBACK POSSIBILITY

If one can show increased correlation of the EEG activity during mental processing, one would then have the means of feeding back some measure of this correlation to the subject. This feedback could have the possibility of acting as a reinforcer of the mental task undertaken. As such it could then be used as a learning tool. An example would be the use of such feedback to reinforce proper recognition of the patterns on ASW phonograms.

IV. METHODS

A. SYNDET

1. Cross Correlation

The measure of the similarity (or dissimilarity) of two time functions may be obtained by computing the cross correlation ($R_{xy}(\tau)$) of the two functions, which is represented by the formula:

$$R_{xy}(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} x(t)y(t-\tau)dt. \tag{4.1}$$

In EEG analysis the x(t) would represent the output from one electrode and y(t) would be the output from a second electrode. The problem one encounters with this formula is that the cross correlation involves averaging. Averaging tends to blur things, which is an undesirable feature when one is trying to obtain localized data.

2. Synchronous Detection

To obtain a measure of correlation without the undesirable blurring, Professor Marmont wrote a program called SYNDET (an acronym for synchronous detection). This program takes continuous input data in block form from separate electrodes, digitally filters the input from each electrode, multiplies them together and displays the results, thus giving what may be called a "running cross-correlation." This program has two advantages: It takes advantage of the sinusoidal nature of the filtered EEG to provide recognizable correlation output patterns, and it causes no blurring effects.

A simple example of how synchronous detection works is to take two constant amplitude sinusoid signals and multiply them together, i.e., let $f(t) = \cos(\omega_1 t) \cos(\omega_2 t + \theta)$. The result is $f(t) = \frac{1}{2} \cos(\omega_1 t - \omega_2 t - \theta) + \frac{1}{2} \cos(\omega_1 t + \omega_2 t + \theta)$ or the sum and different frequencies. If ω_1 equals ω_2 and $\theta = 0$, $f(t) = \frac{1}{2} + \frac{1}{2} \cos 2\omega_1 t$. If ω_1 equals ω_2 and θ equals π, $f(t) = -\frac{1}{2} + \frac{1}{2} \cos 2\omega_1 t$. For any other combinations of frequency and phase, we get a resultant signal composed of the slowly varying difference frequency and the faster sum frequency.

B. THE COMPUTER MODELING PROGRAM

In order to understand better the output from the SYNDET program and what it represents, a series of modeling programs were written by the author. These programs, called MODSYN, were designed to manufacture representative tegule models and multiply them together. The output was then compared to SYNDET outputs to help model the causes of certain SYNDET patterns, especially when changes of phase and frequency occurred in the signals being multiplied together.

The major functional parts of the modeling program were: sinusoid generation, envelope generation, filtering and display. The modeling program used the same computers and hardware as was used in the research project. Therefore the model was processed in the same manner as the EEG data.

1. Sinusoid Generation

Mathematical functions were used to generate the necessary sinusoids. The Time Series Language (TSL) software

used with the PDP 11/40 is especially designed for block manipulations for the processing of data. Input data is divided into blocks. These blocks may then be manipulated as though they were separate entities. The programmer specifies block size in number of elements, type and format of data, and sampling rate. The modeling program used a block size of 1024 elements and a sampling rate of 512 elements per second. Each block word was chosen to represent one sample taken every 1/512 second. To generate a sinusoid one first loaded the block with sample points representing the appropriate phase function, $\theta(t)$, for each sample point. One then takes the cosine via software routine of $\theta(t)$ so the block when displayed gives the desired sinusoid. A tegule was manufactured by generating either a constant frequency sinusoid or a linear period sweep sinusoid, then generating an envelope sinusoid, and multiplying the two together.

a. Constant Frequency Sinusoid

A constant frequency sinusoid was generated using the formula:

$$B(n) = \cos 2\pi f n a \tag{4.2}$$

where

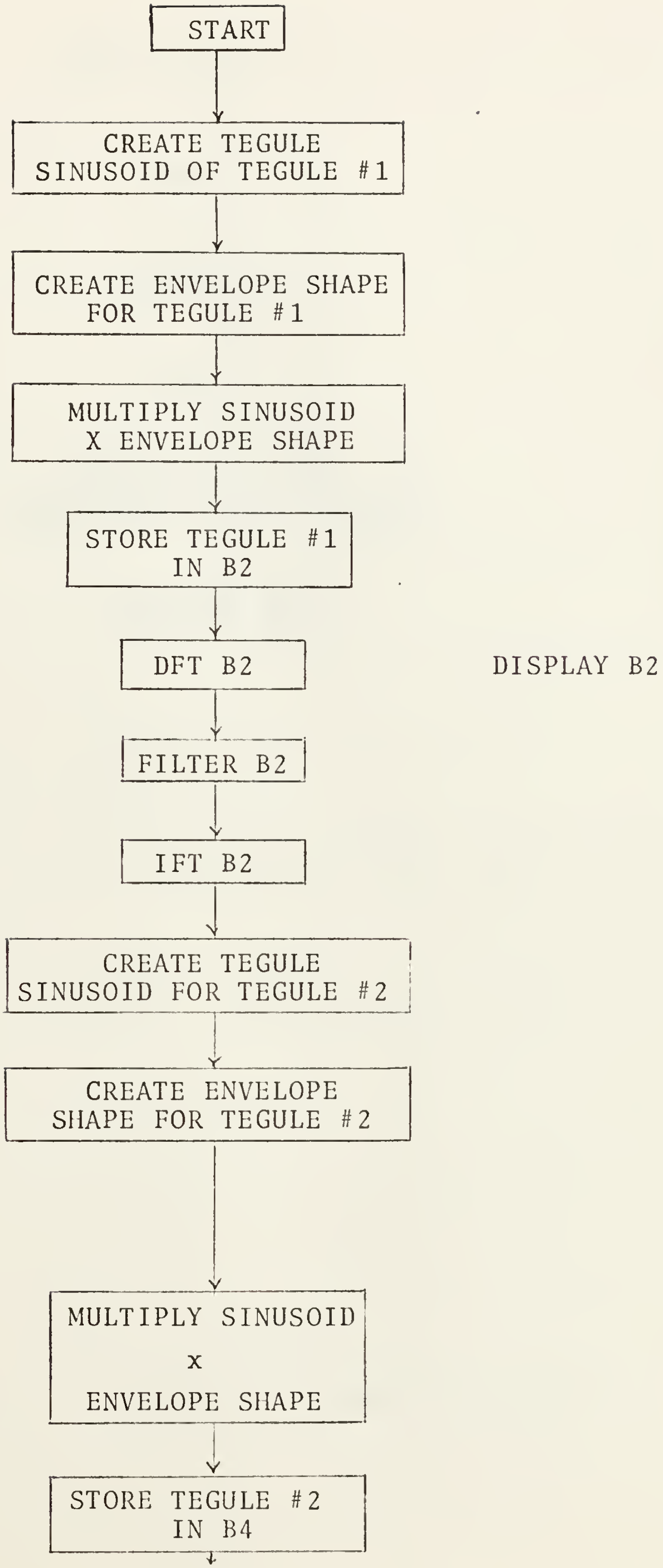
$B(n)$ equals the magnitude of the n^{th} block element,

f equals the desired frequency,

n equals the sample point number which varies from zero to 1023,

a equals 1/512,

na equals time ($0 \leq t \leq 2$ sec).


START
CREATE TEGULE SINUSOID OF TEGULE #1
CREATE ENVELOPE SHAPE FOR TEGULE #1
MULTIPLY SINUSOID X ENVELOPE SHAPE
STORE TEGULE #1 IN B2
DFT B2
DISPLAY B2
FILTER B2
IFT B2
CREATE TEGULE SINUSOID FOR TEGULE #2
CREATE ENVELOPE SHAPE FOR TEGULE #2
MULTIPLY SINUSOID
x
ENVELOPE SHAPE
STORE TEGULE #2 IN B4

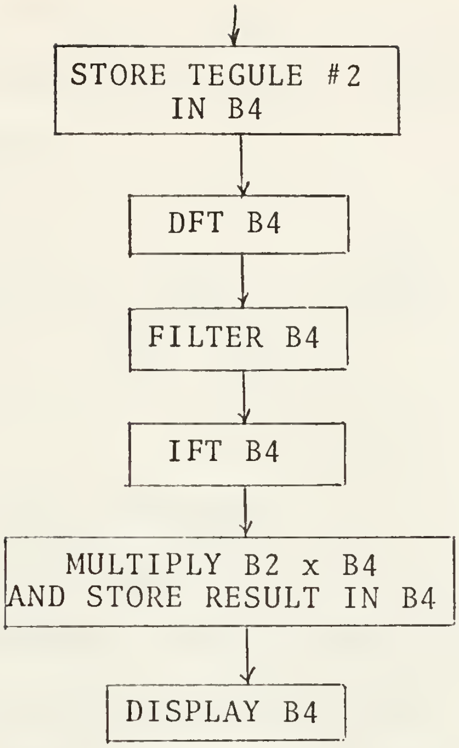


Figure 4-1. Flow Chart for MODSYN Program.

b. Linear Period Sweep Sinusoid

A linear period sweep sinusoid was generated using the formula:

$$B(n) = \cos\{\frac{2\pi\tau}{\frac{1}{f_2} - \frac{1}{f_1}} \ell n[\frac{(\frac{1}{f_2} - \frac{1}{f_1})f_1 \, na}{T} + 1]\} \qquad (4.3)$$

where

f_1 equals start frequency,

f_2 equals final frequency,

T equals duration time of sweep (for the models shown in Figs. 5-1 to 5-13, T equals one sec,

n equals sample point number ($0 \leq n \leq 511$),

B(n) equals n^{th} block element.

2. Constant Frequency Tegule

The most commonly observed tegule type was the constant frequency tegule. A model for this type was generated using the formula:

$$B(n) = \{[1-\cos 2\pi f_e(na-\lambda) \cos 2\pi f_o(na-\lambda)\}, \qquad (4.4)$$

where

f_o equals tegule frequency,

f_e equals envelope frequency,

λ equals time delay,

B(n), n, a, same as for Eqn. (4.2).

The time delay, λ, was inserted to model the effects of phase shift of one tegule relative to another. The time delay was varied in incremental steps $\lambda = t_o/k$, where $t_o = 1/f_o$ and

$k = 0,1,2,\ldots 8$. Figure 4-2 shows a representative constant frequency tegule model.

3. Linear Period Sweep Tegule

The other type of observed tegule was the linear period sweep tegule. It was modeled using the formula:

$$B(n) = (1-\cos 2\pi f_e(na-\lambda))\cos \frac{2\pi\tau}{\frac{1}{f_2}-\frac{1}{f_2}} \ell n \left[\frac{\frac{1}{f_2}-\frac{1}{f_1}}{T} f_1(na-\lambda)+1\right]\}$$

where

f_2 equals final frequency,

f_1 equals envelope frequency,

T equals tegule duration,

λ equals time delay.

Figure 4-3 shows a representative linear period sweep model.

4. Filtering

In order to approximate the SYNDET program the generated tegule was filtered to some desired bandwidth. This was accomplished by DFTing the tegule block, zeroing the unwanted frequencies, and then IFTing the block.

5. Record of Events

After being generated and filtered, the two tegule blocks were multiplied together. The results were then displayed and plotted.

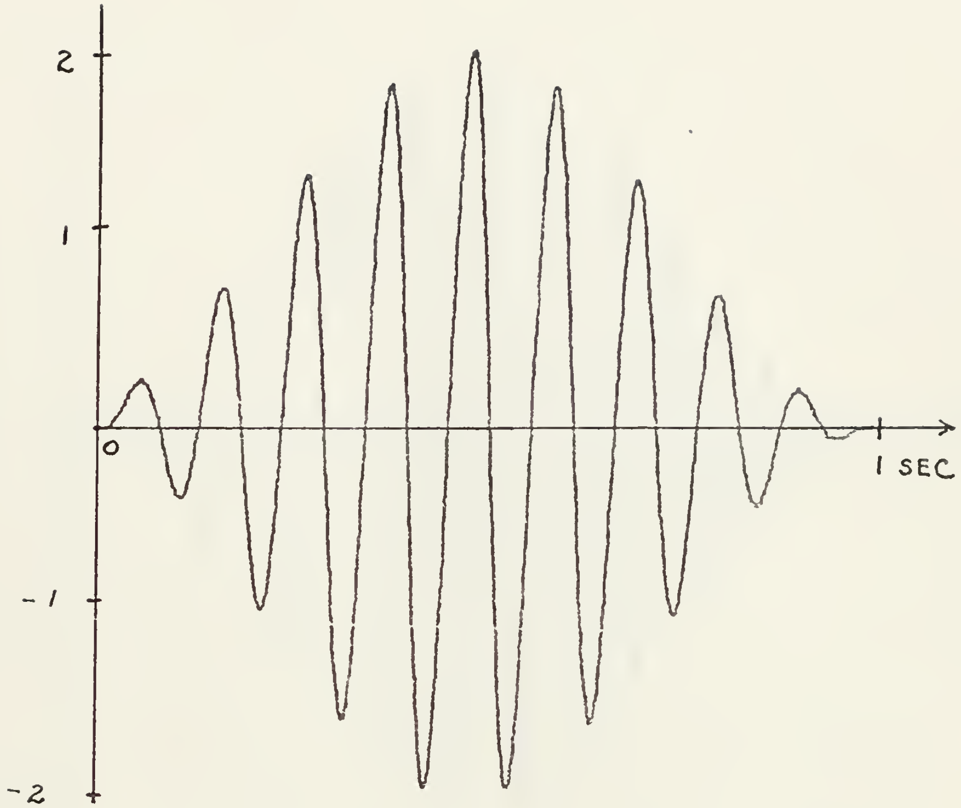


Figure 4-2. Constant frequency tegule.
(f = 10 Hz)

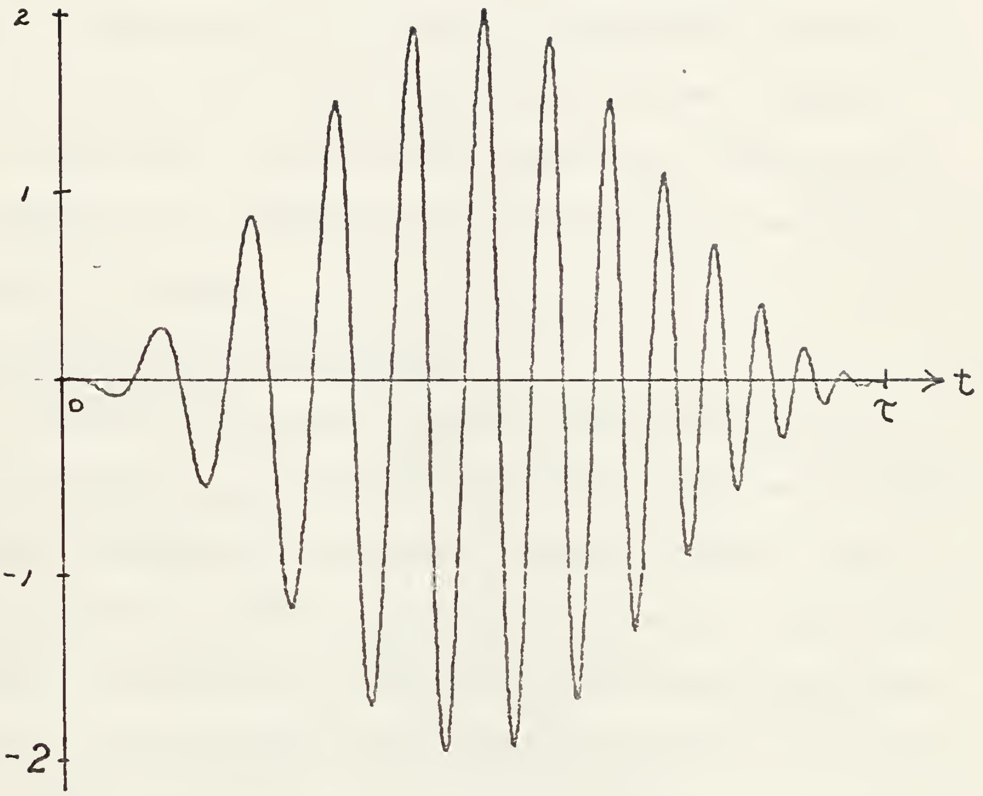


Figure 4-3. Linear period sweep tegule.
(f_1 = 4 Hz, f_2 = 12 Hz, f_{env} = 1 Hz)

V. RESULTS

A. MODELS

The following figures will show representative results of multiplying two tegules of various frequencies and phase together. In each figure, the top trace displays tegule number one, the middle trace tegule number two, and the bottom trace displays the SYNDET pattern obtained by multiplying the two tegules together.

1. Constant Frequency Tegules

Two constant frequency tegules, each having an f_o equalling 15 Hz and f_{env} equalling one Hertz were multiplied together using different time delays for the second tegule relative to the first tegule. The time delay was varied in $\lambda = \frac{1}{8} t_o$ steps. Figures 5-1 through 5-8 show some representative results. We see that two identical tegules coincident in time give the largest SYNDET response. The low points of the sinusoid all rest upon the zero axis, a characteristic common to all cases where the time delay is an integral multiple of t_o. For $\lambda = \frac{2n-1}{2} t_o$, we see the high points of the SYNDET response all rest on the zero axis. For cases where $\lambda = \frac{2n-1}{4} t_o$ the resultant wave form resembles a higher frequency tegule.

Figures 5-9 and 5-10 show the result of multiplying two constant frequency tegules of different frequencies together.

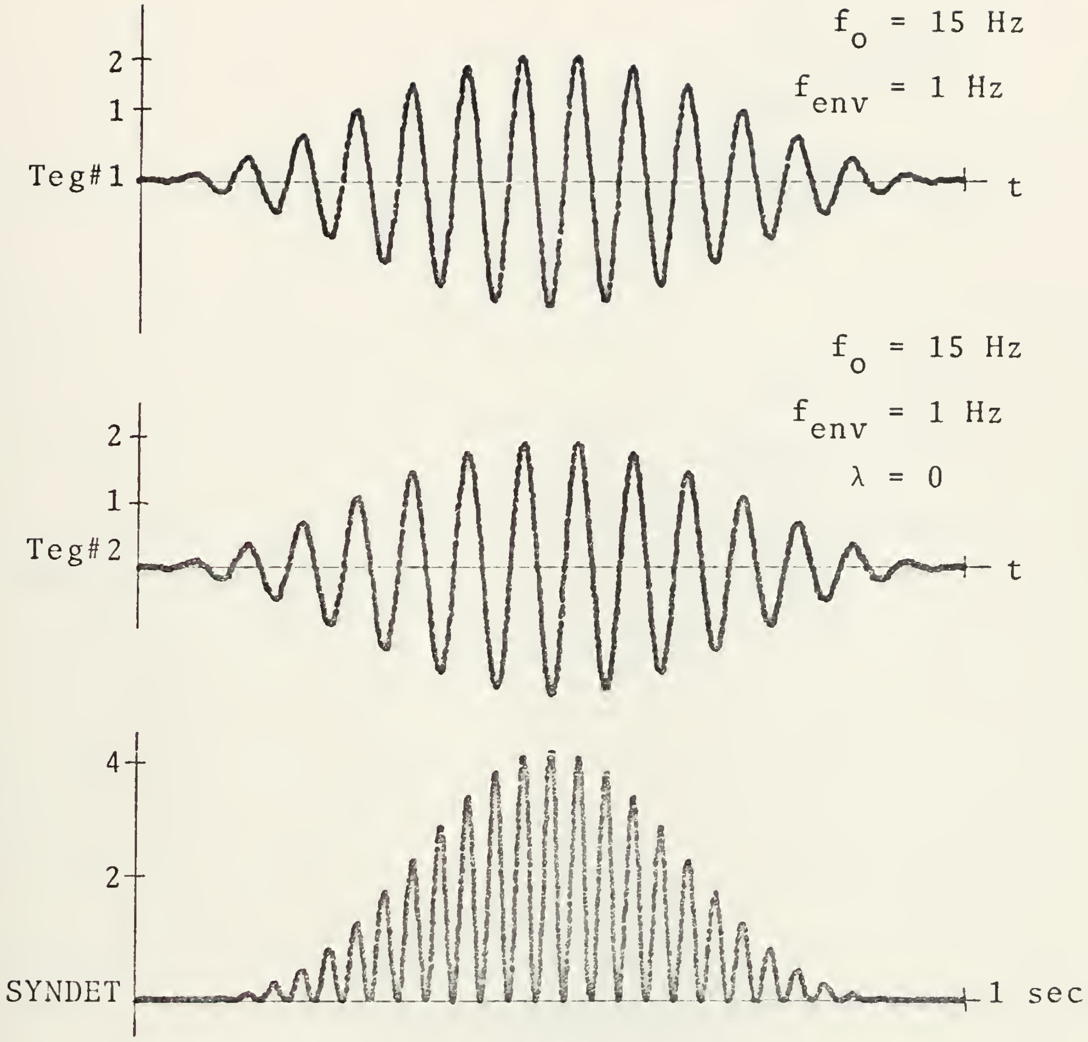


Figure 5-1. SYNDET display resulting from two identical constant frequency tegules with no time delay (i.e. $\lambda = 0$).

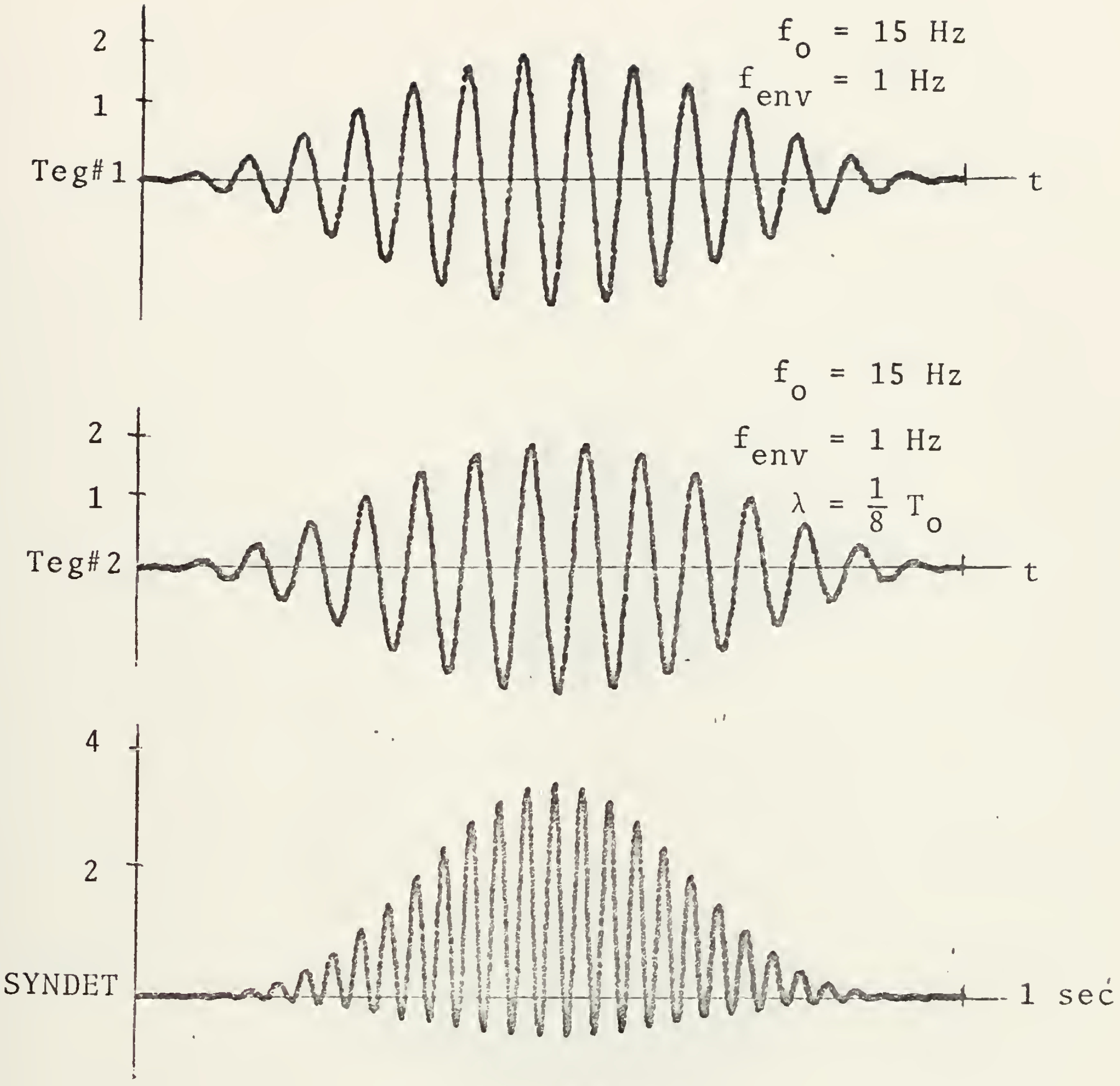


Figure 5-2. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 1/8\ T_o$.

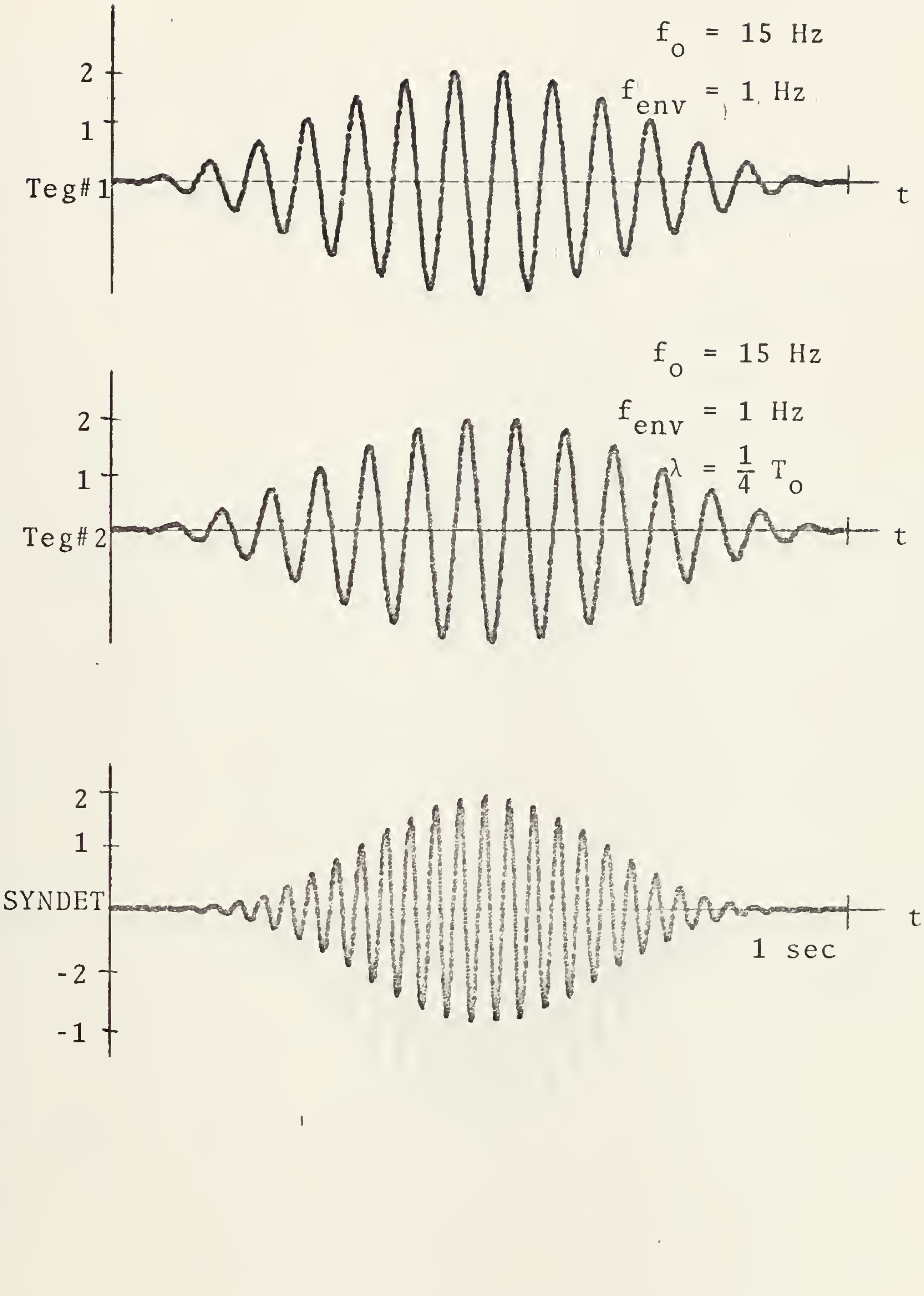


Figure 5-3. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 1/4\ T_o$.

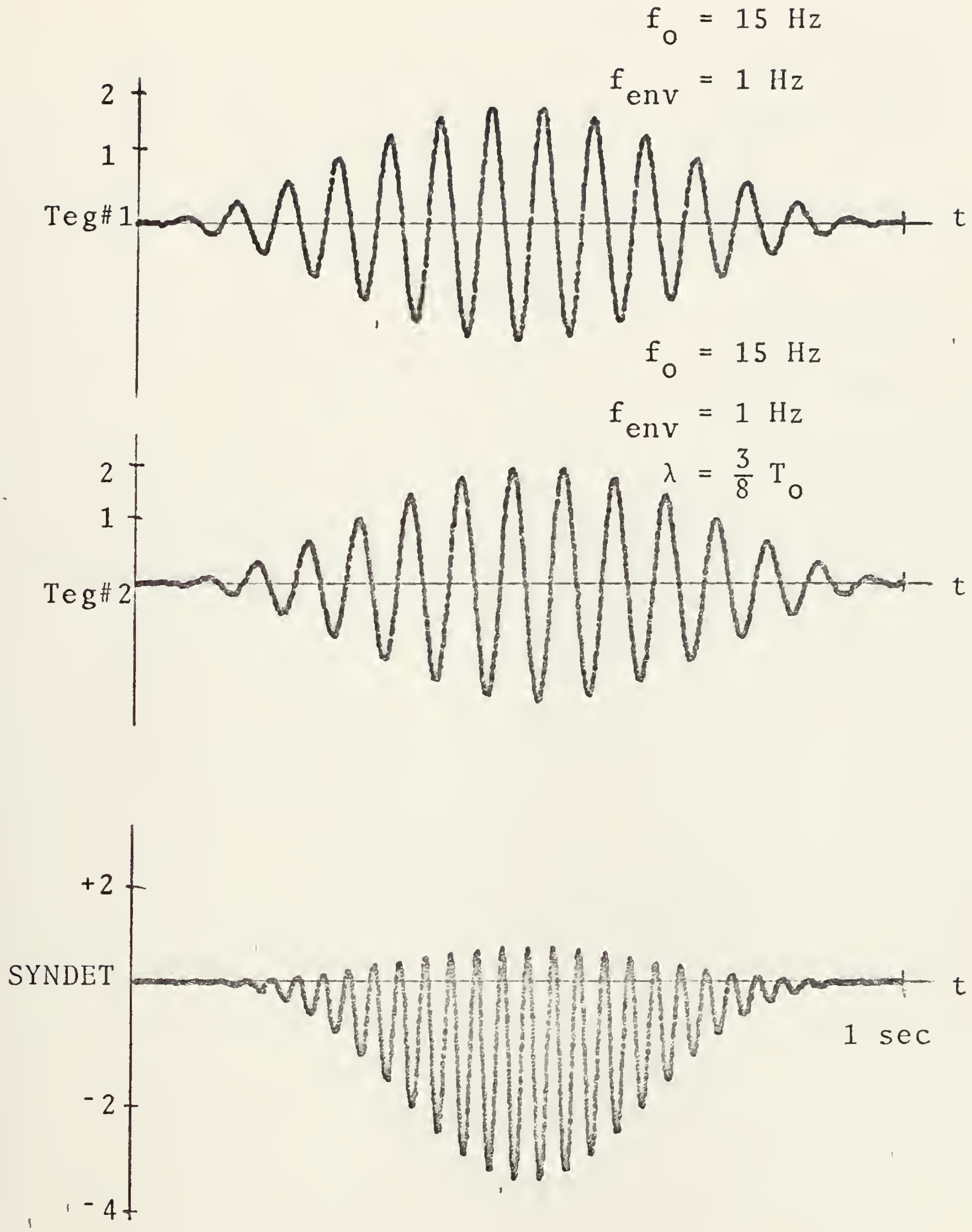


Figure 5-4. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 3/8\ T_o$.

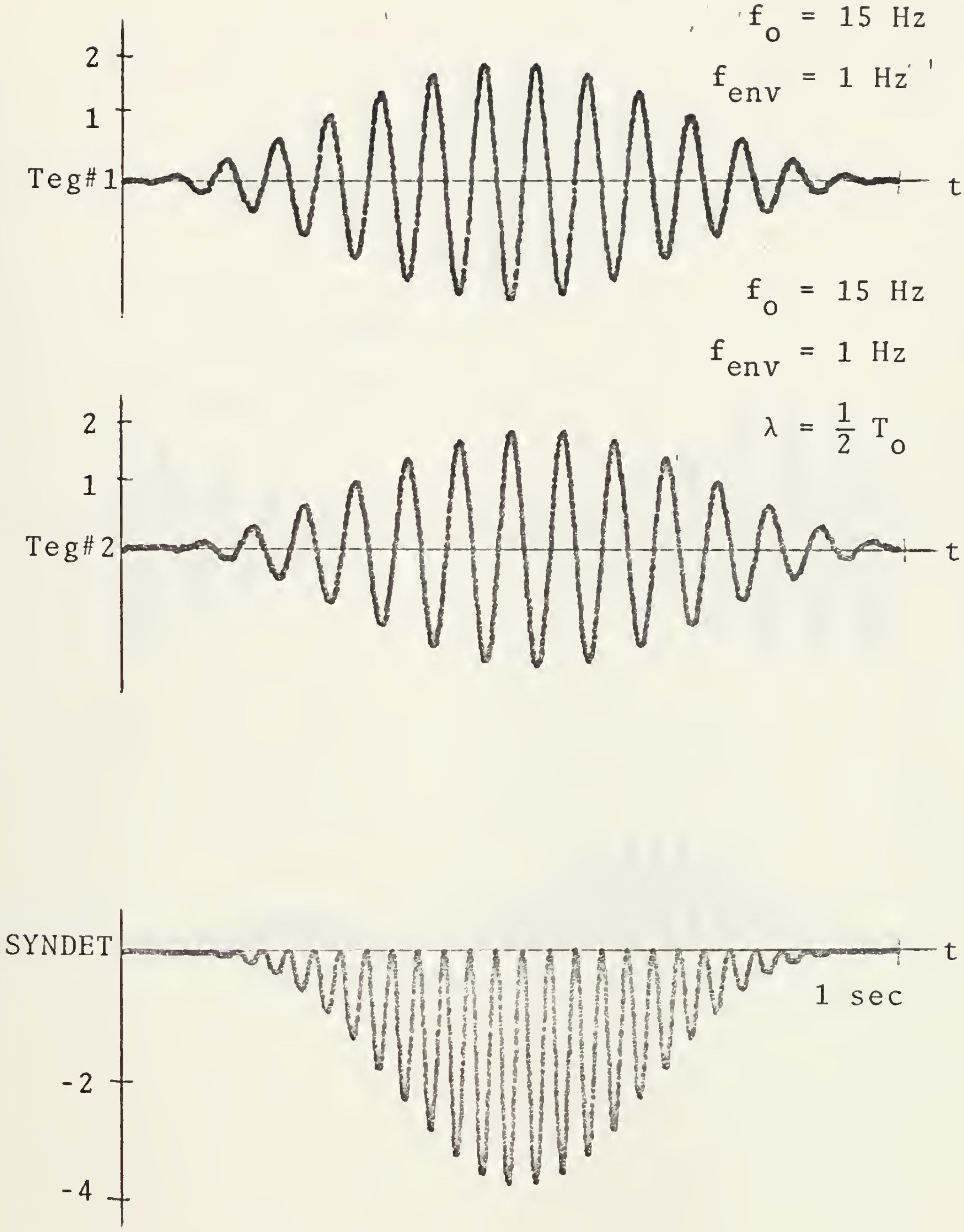


Figure 5-5. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 1/2\ T_o$.

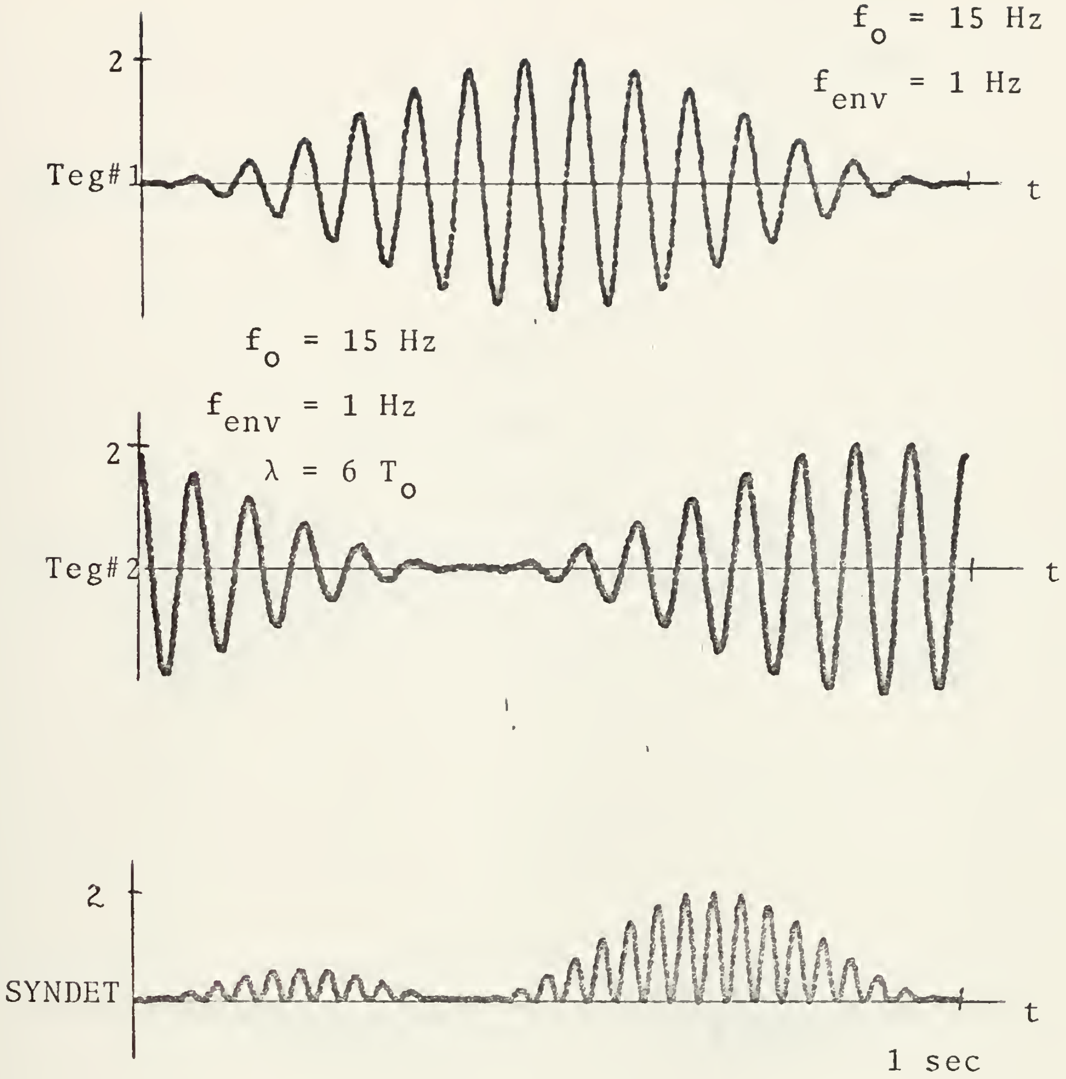


Figure 5-6. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 6\ T_o$.

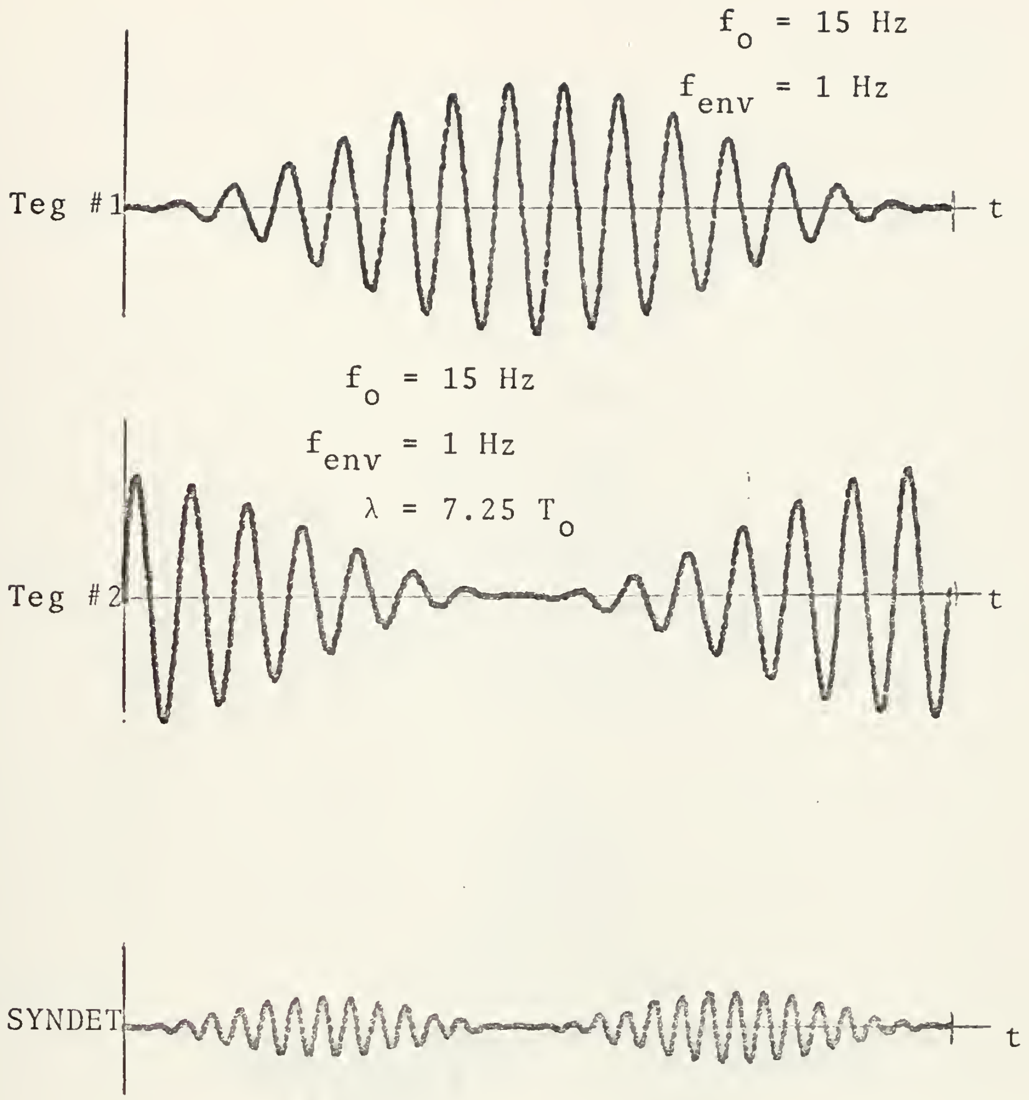


Figure 5-7. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 7.25\ T_o$.

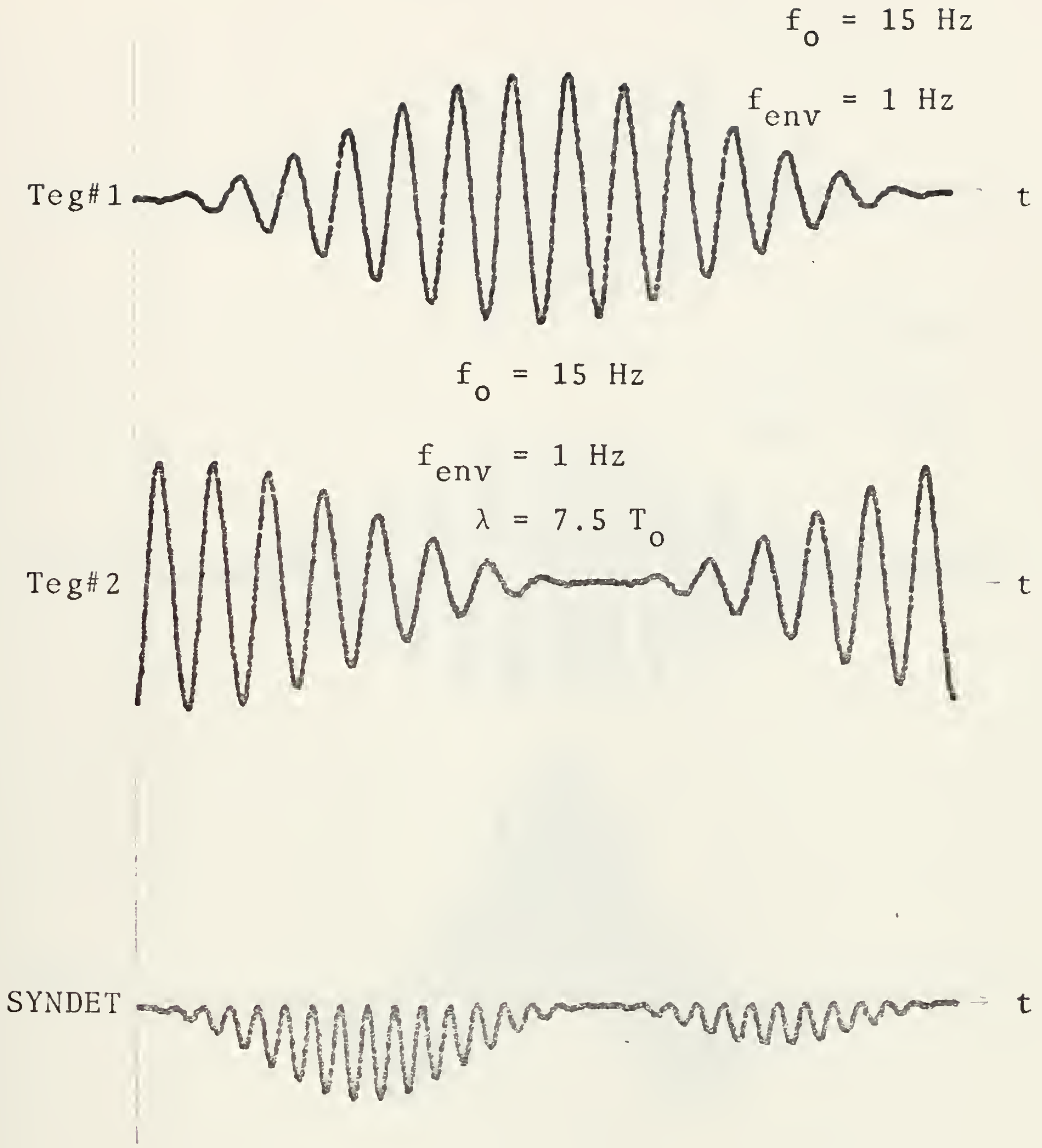


Figure 5-8. SYNDET display resulting from two identical constant frequency tegules with time delay $\lambda = 7.5\ T_o$.

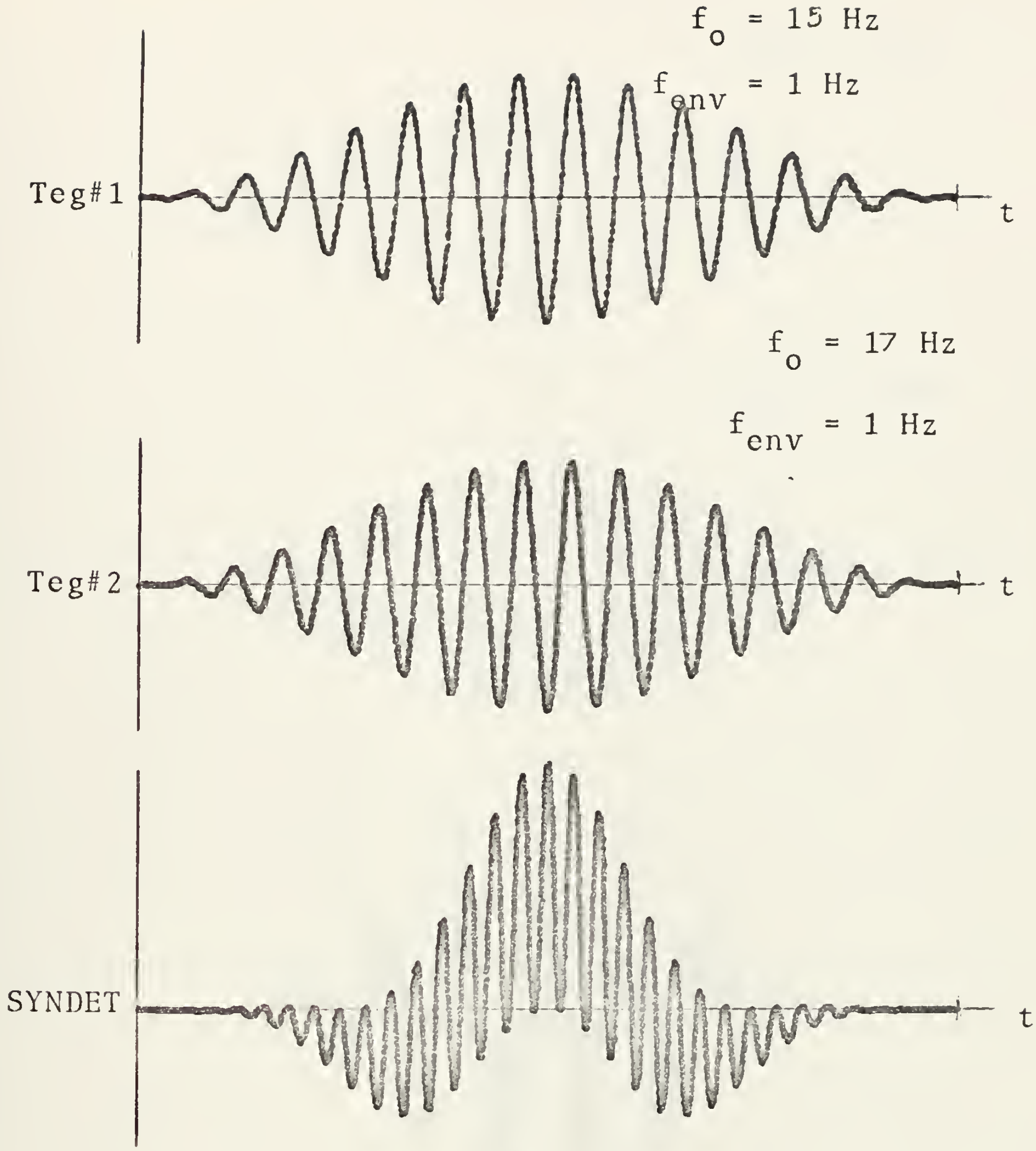


Figure 5-9. SYNDET display resulting from two constant frequency tegules of different frequency.

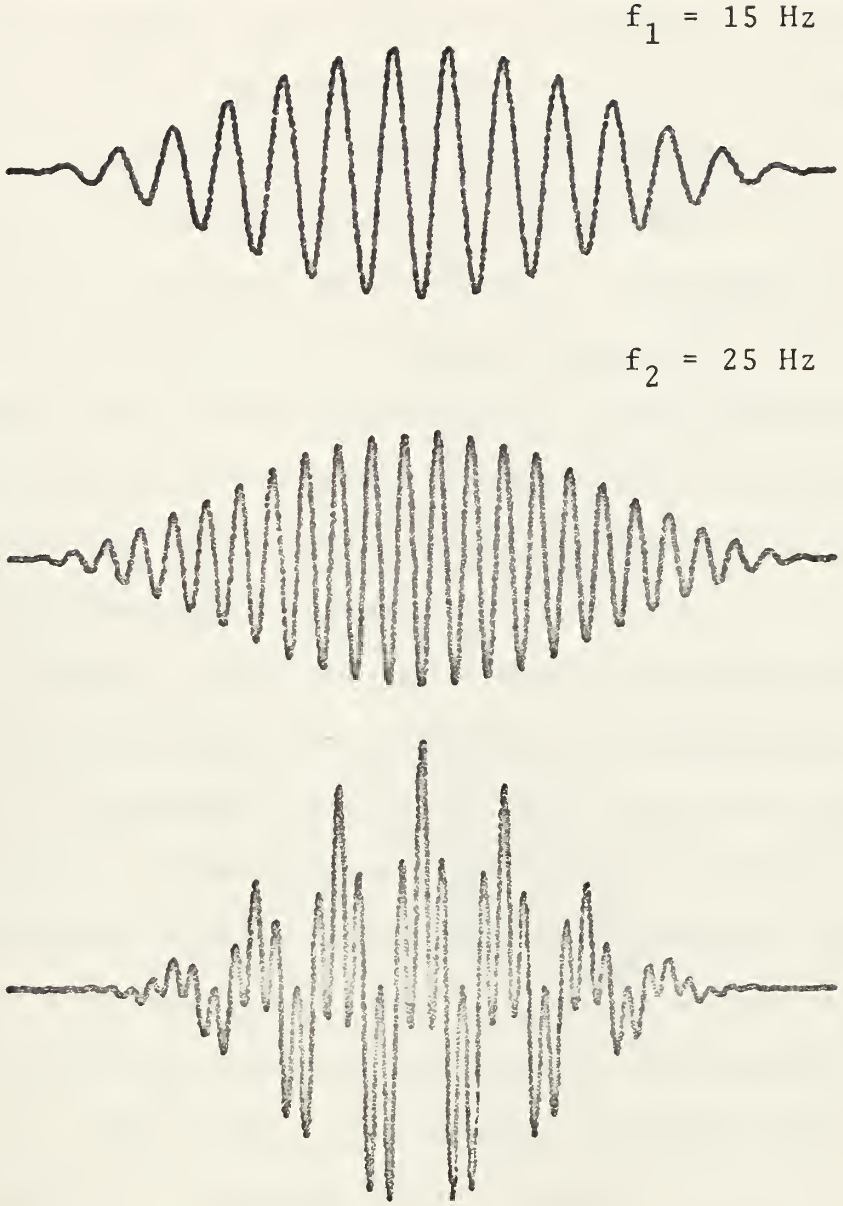


Figure 5-10. SYNDET display resulting from two constant frequency tegules of different frequency being multiplied together.

2. Linear Period Sweep Tegules

Two linear period sweep tegules were multiplied together using different time delays and different frequencies. It was observed that the result for $\lambda = 0$ (no time delay) had the same characteristic shape as that observed for $\lambda \equiv 0$ in the constant frequency case. For cases where $\lambda \neq 0$, the resultant SYNDET patterns were "skewed." The pattern and amount of skew depended on the sweep frequencies. The patterns observed when different frequency linear period sweep tegules were multiplied together were similar to the constant frequency case but with a skew effect. Figures 5-11 through 5-14 show representative models.

In summary, the models show that synchronous detection is a sensitive and clear indicator of correlation between two signals. Synchronous detection then, gives one a good measure of what is common to two electrode lead offs. It takes advantage of the sum and difference frequency patterns which result from multiplying two sinusoidal signal together. Changes of phase and frequency are clearly discernible and can be readily identified. The results of SYNDET runs show patterns similar to the above model results.

B. COMPARISON OF ACTUAL SYNDET RECORDS WITH MODELS

The actual SYNDET records consist of fan-fold chart recordings consisting of six traces. Each trace is approximately 93 inches long and represents 18 consecutive one-second frames of data. Traces one, three and five are EEG's from electrodes one, two, and three. Trace two is the SYNDET of electrodes

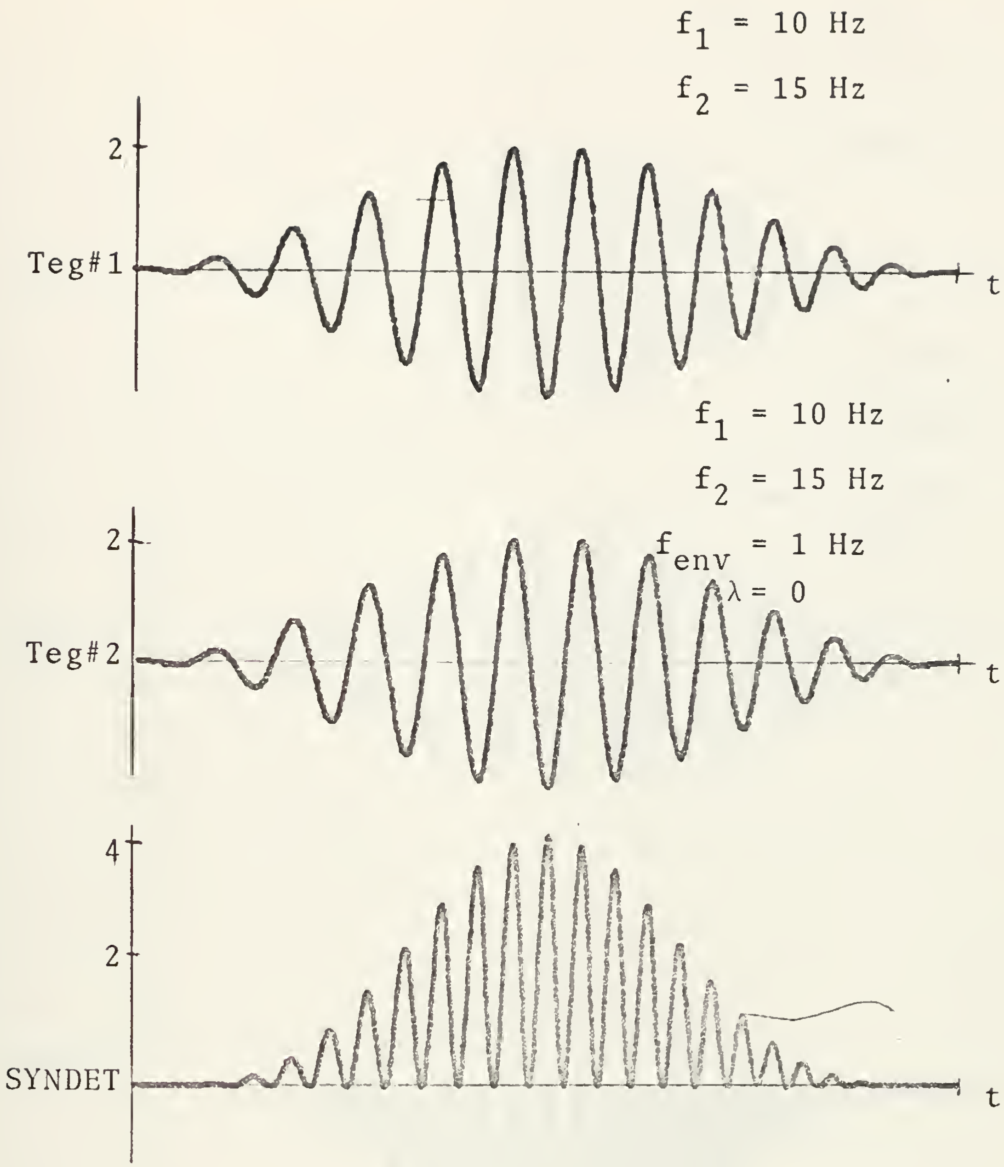


Figure 5-11. SYNDET display resulting from two identical linear period sweep tegules with no time delay (λ=0).

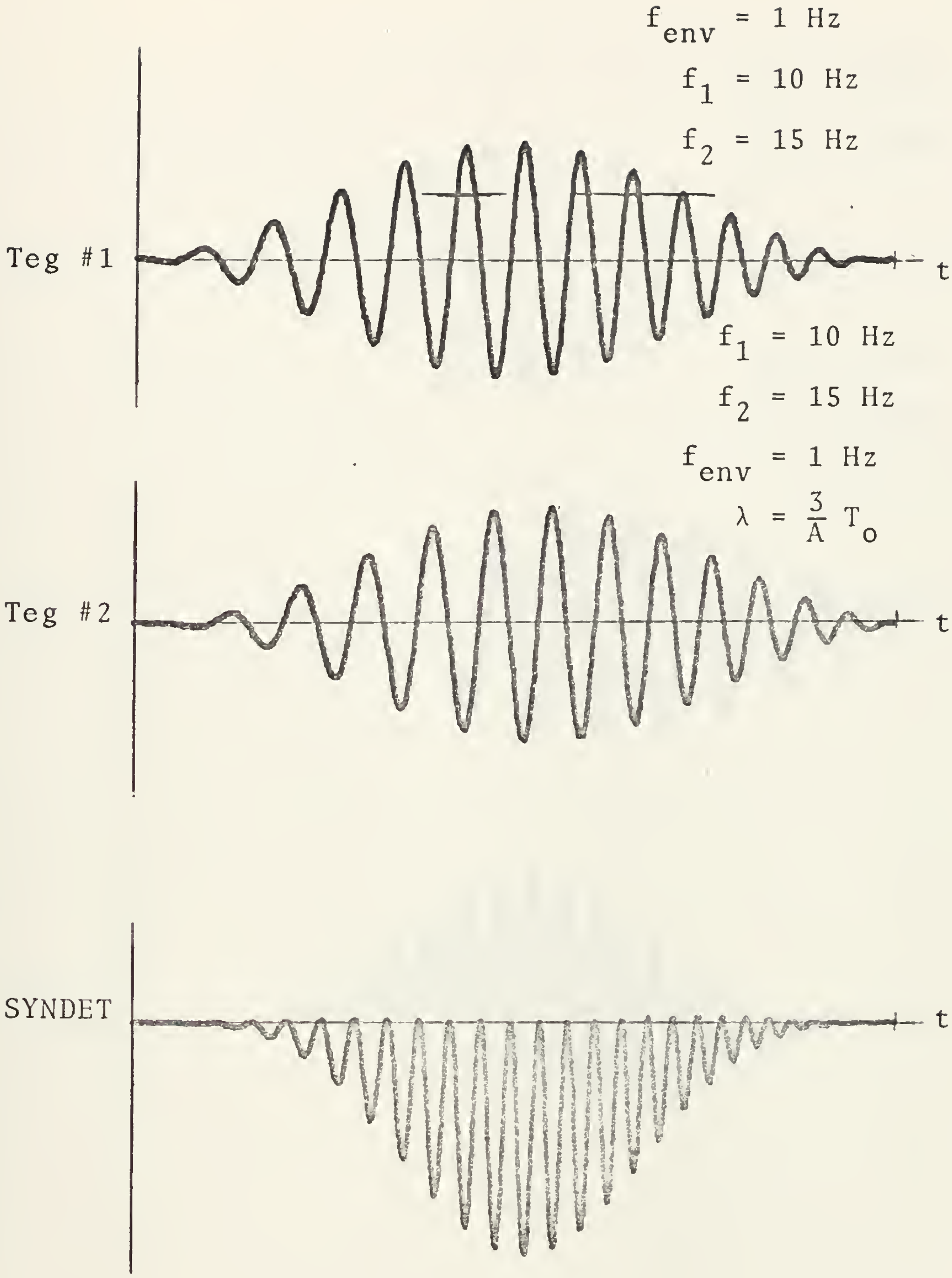


Figure 5-12. SYNDET display resulting from two identical linear period sweep tegules with time delay $\lambda = .0375$ sec $= 3/A\ T_o$.

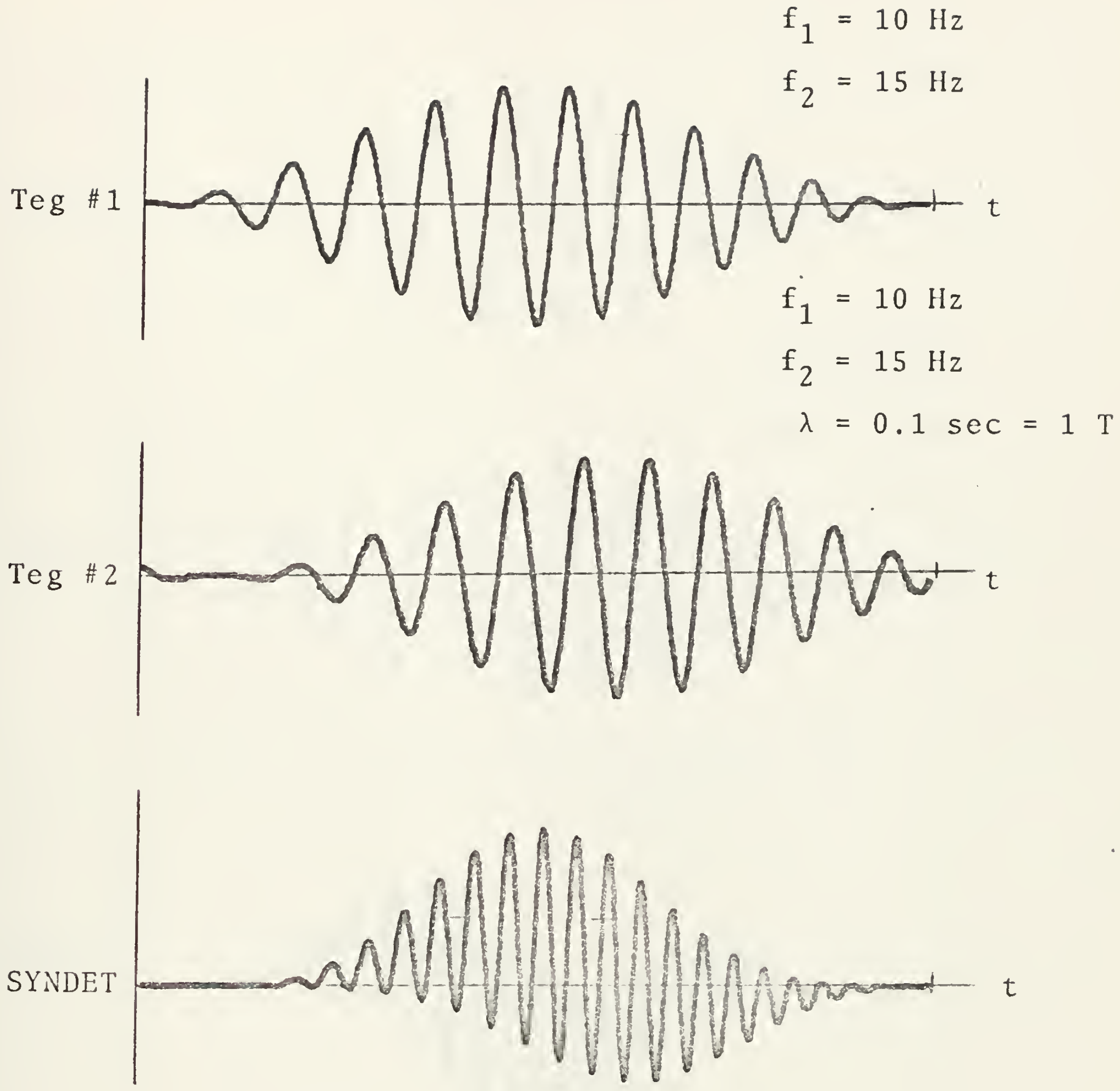


Figure 5-13. SYNDET display resulting from two identical linear period sweep tegules with time delay $\lambda = 0.1$ sec = 1 T. NOTE: the skew of the SYNDET pattern.

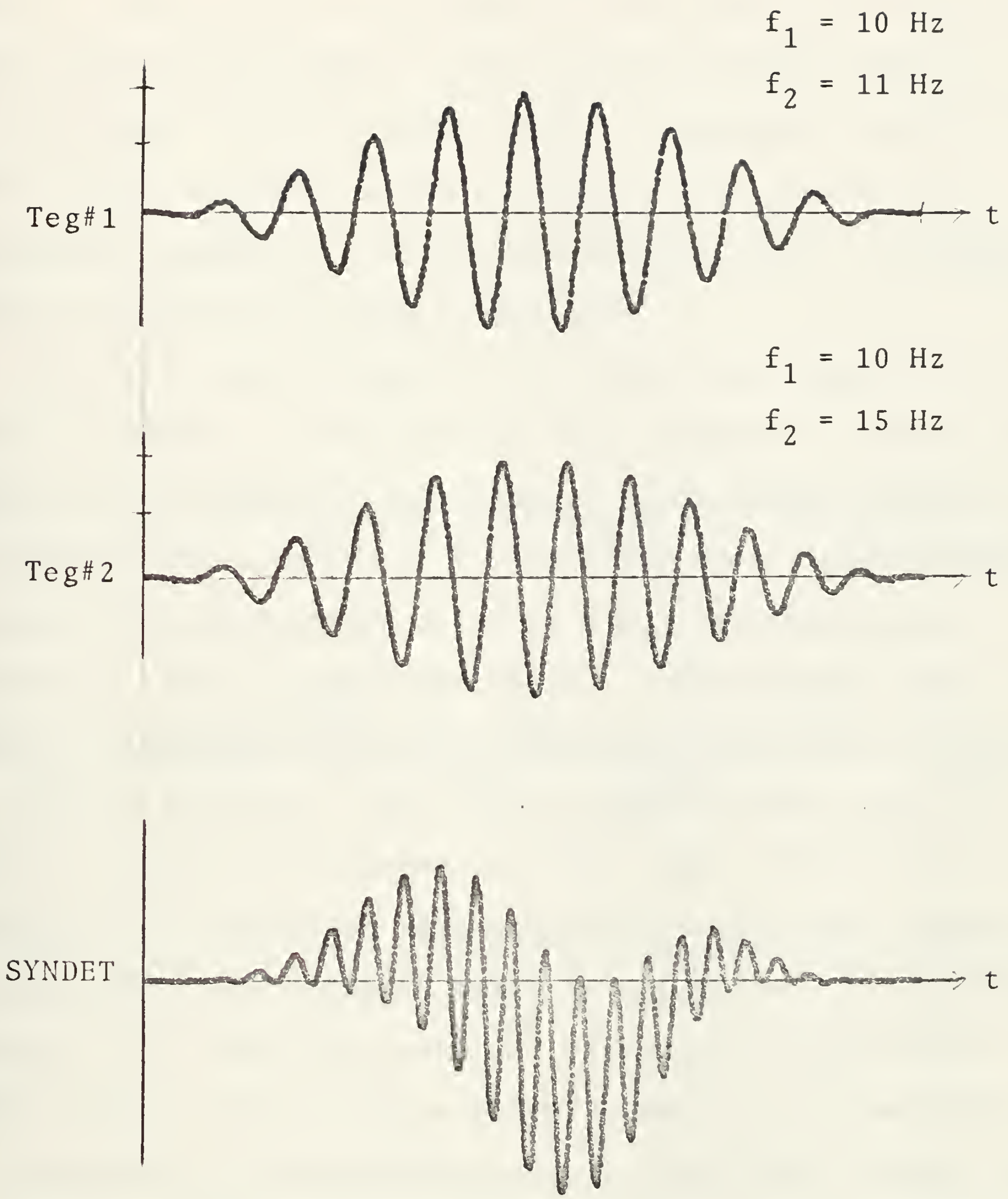


Figure 5-14. SYNDET display resulting from two different linear period sweep tegules.

one and two. Trace four is the SYNDET of electrodes two and three. Trace six is the SYNDET of electrodes three and one. The trace lengths shown in the figures represent about one and one half seconds worth of data. Electrodes one and two were closely spaced and usually placed over the dominant hemisphere temporal-occipital-parietal junction. Electrode three was placed in various locations.

The data runs were made in 100 frame (one frame per second) increments. A typical run would consist of twenty five frames eyes closed-relaxed followed by 65 frames of eyes closed-problems, ending with ten frames eyes closed-relaxed again. The problems consisted of simple multiplication problems. Each run was done using a chosen filter bandwidth. Bandwidth frequencies used have been 5-25, 15-30, 30-45, and 65-85 Hz. The 5-25 Hz bandwidth was chosen in order to include low frequencies and alpha. The 15-30, 30-45, and 65-85 Hz bandwidths were selected because they encompassed preferred frequency bands as determined by the HISCAN program. The full 100 frame run was stored on disk from which the selected 18 frame SYNDET segments were recorded.

Figures 5-14 through 5-16 show actual SYNDET traces. The circled traces are similar to those modeled. The number next to each circle refers to the figure number of the model.

C. SYNDET RECORDS WITH AND WITHOUT PROBLEMS

Figures 5-18A through 5-19B show segments of SYNDET runs using the author as a subject. For runs one and two electrodes one and two were placed close together directly over

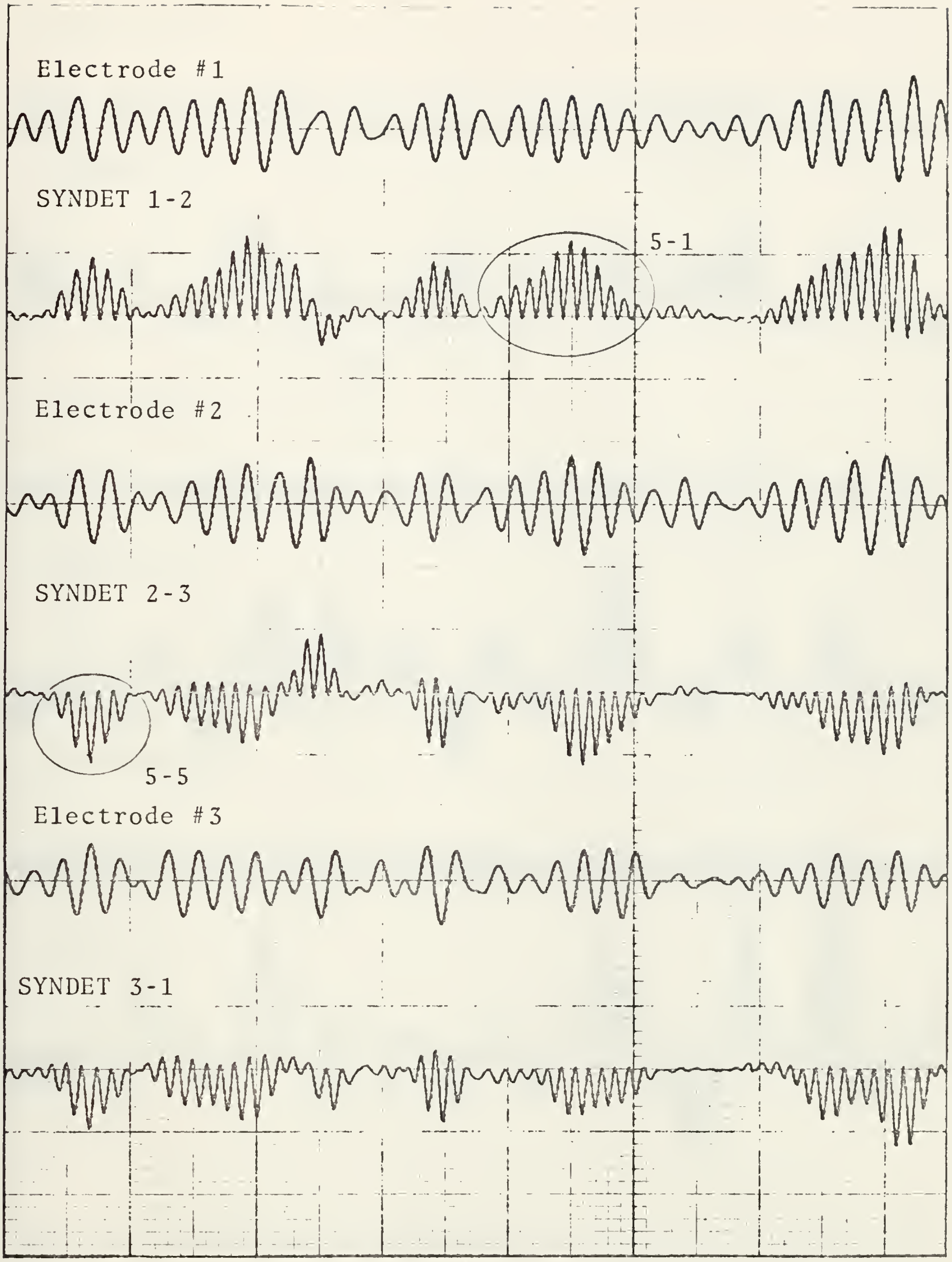


Figure 5-15. SYNDET run: 15-30 Hz, eyes open-relaxed. Circled areas show SYNDET patterns similar to models.

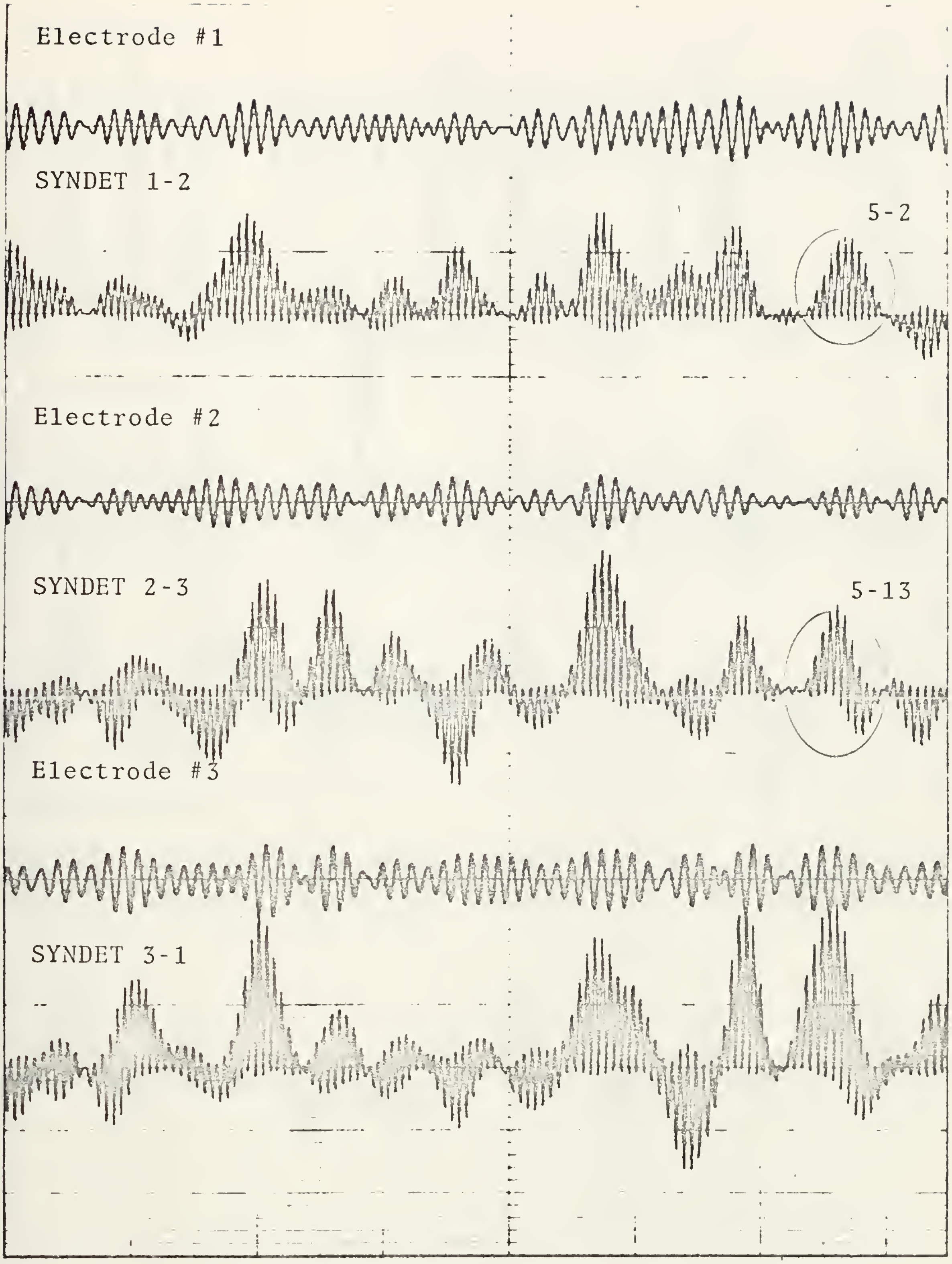


Figure 5-16. SYNDET run: 30-45 Hz, eyes open-relaxed. Circled areas show SYNDET traces similar to models.

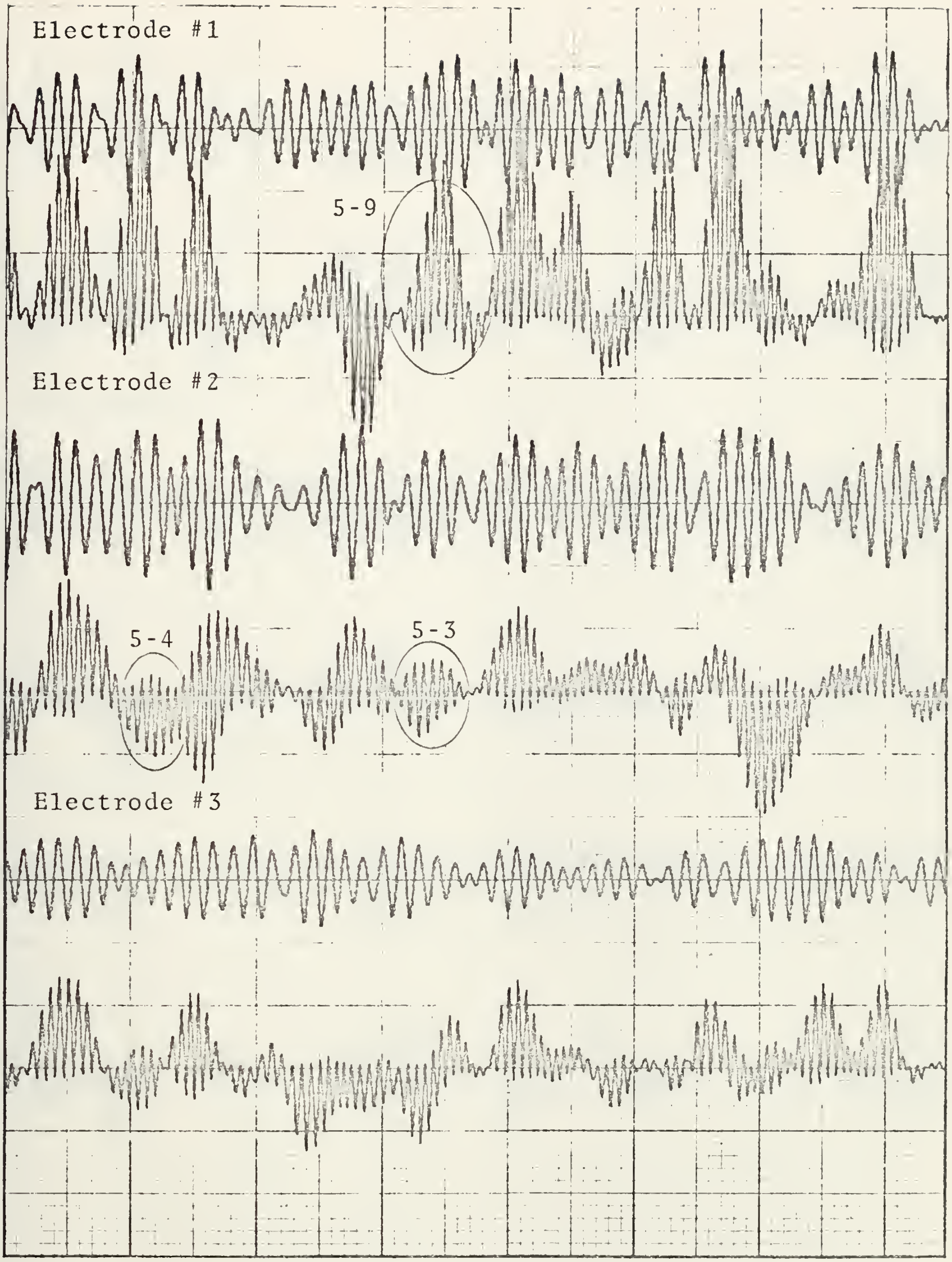


Figure 5-17. SYNDET run: 65-85 Hz, eyes closed-problems. Circled areas show SYNDET traces similar to models.

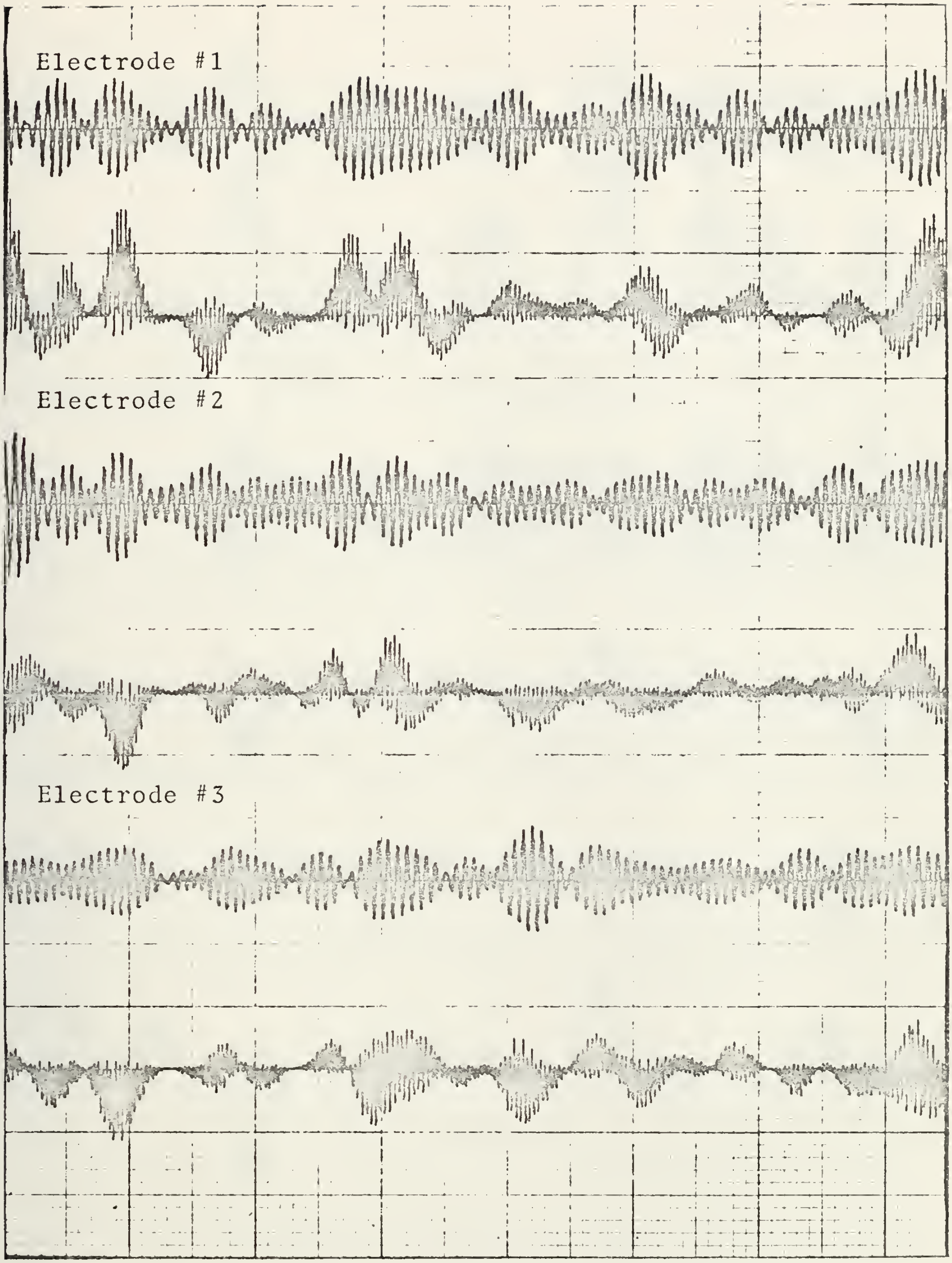


Figure 5-18A. Graph from SYNDET run #2: 65-85 Hz bandwidth, eyes closed-relaxed.

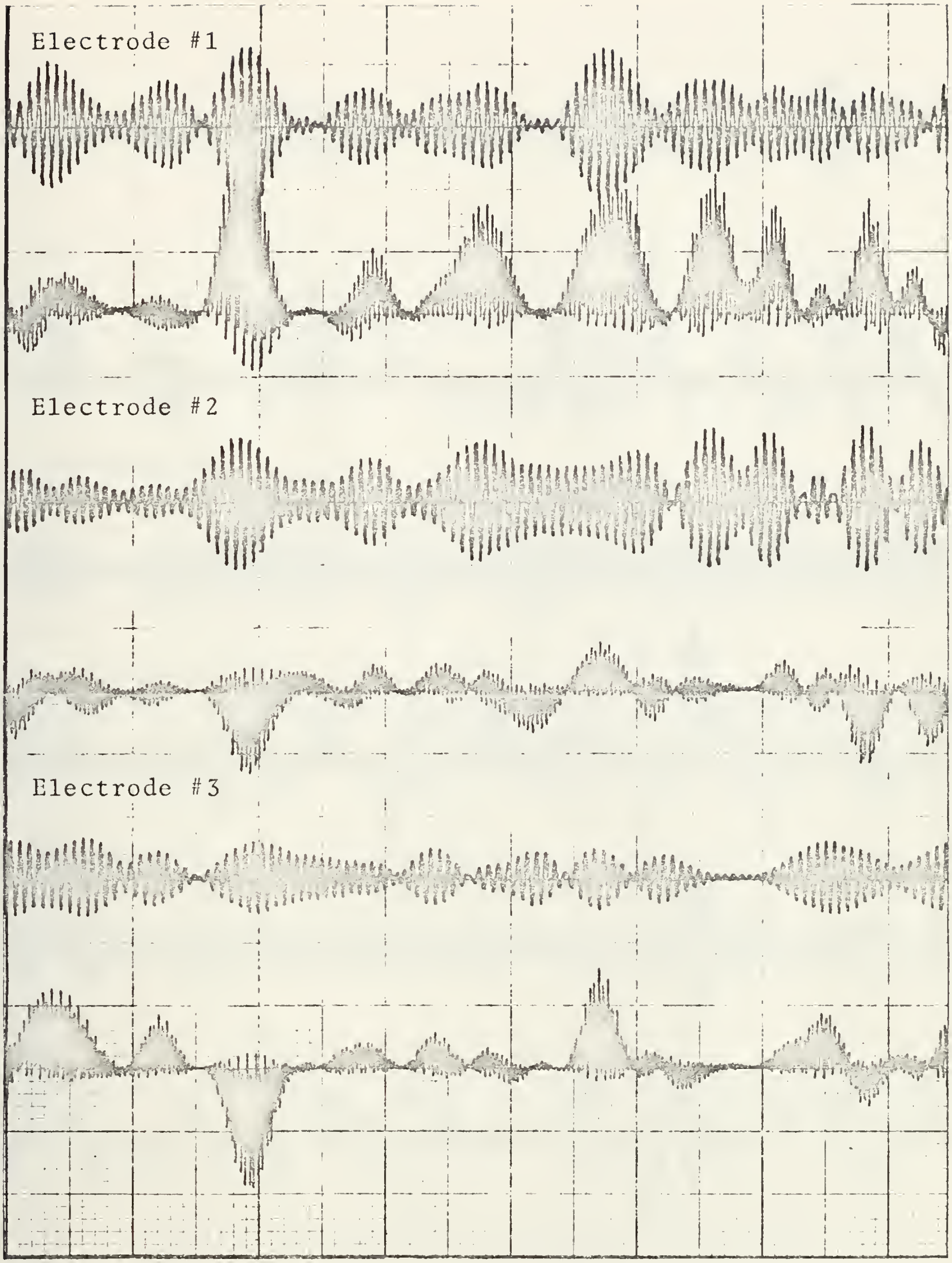


Figure 5-18B. Graph from SYNDET run #1: 65-85 Hz bandwidth eyes closed-problems. Note the increased correlation and height of SYNDET trace 1.

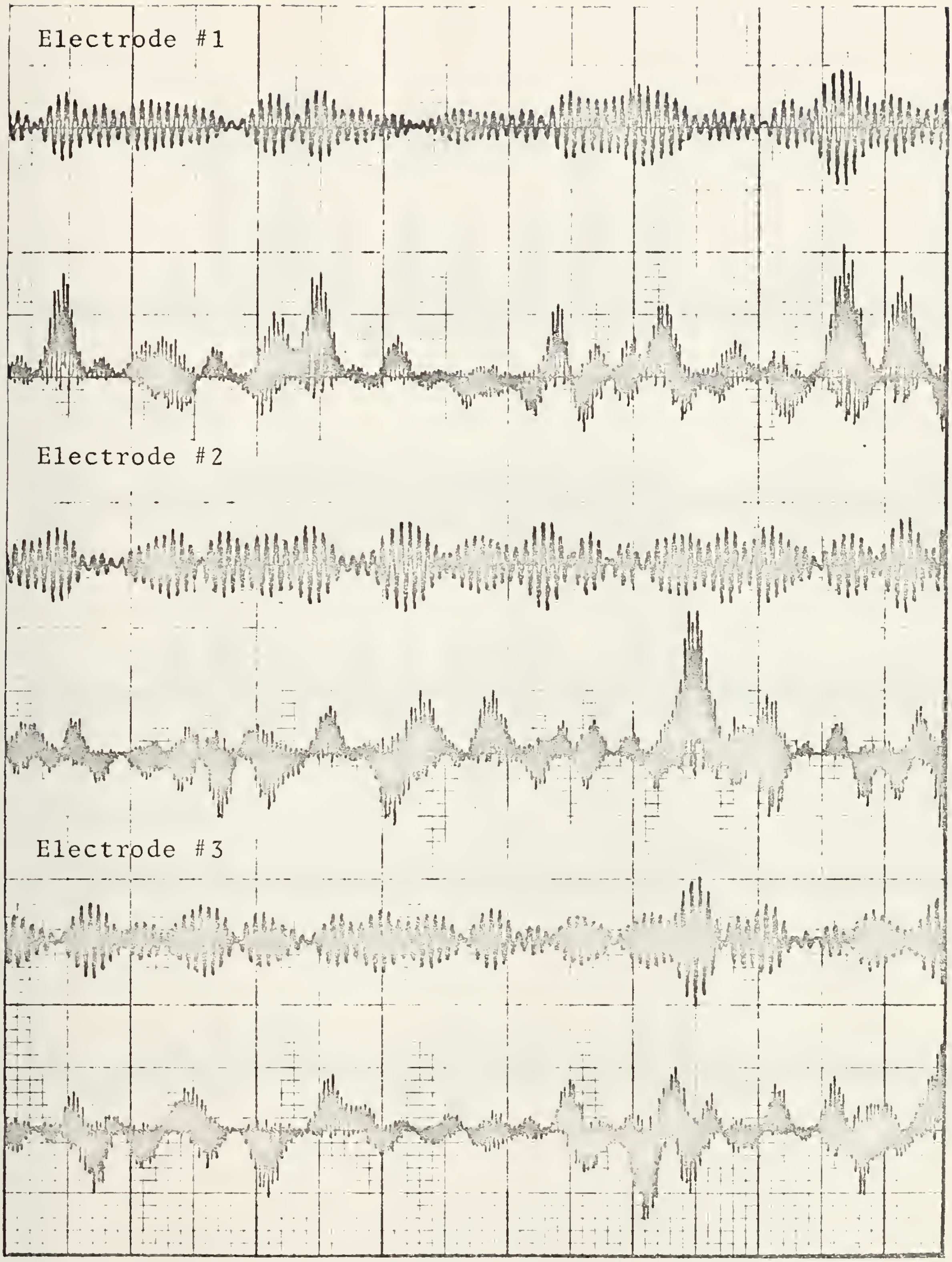


Figure 5-19A. Graph from SYNDET run #3: 65-85 Hz bandwidth eyes closed-relaxed.

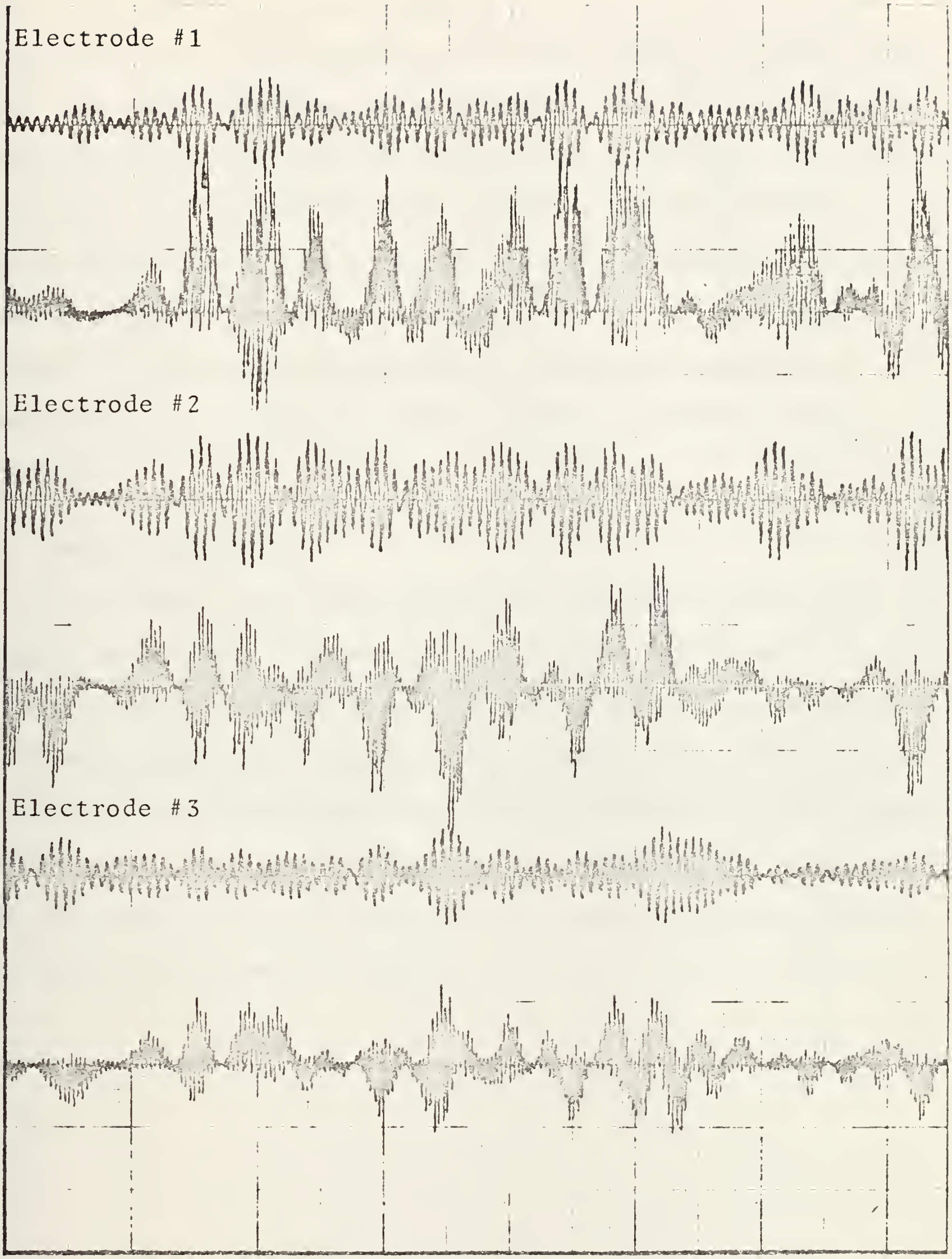


Figure 5-19B. Graph from SYNDET run #4: 65-85 Hz bandwidth, eyes closed-problems. Note again how the level and correlation of SYNDET trace #1 increases.

the left temporal-occipital-parietal juncture (TOP) while electrode three was placed on the left forward parietal area. For runs three and four, electrodes one and two were placed over the right TOP and electrode three was placed over the top center (apex) of the head. The frequency bandwidth of 65-85 Hz was chosen as a result of a HISCAN analysis of preferred frequencies of the author's EEG's. As is shown in Figures 5-18B and 5-19B, there is a definite increase in correlation between electrodes one and two during mental tasking.

D. FRAME INTEGRATION

The SYNDET trace from electrodes one and two was integrated on a frame by frame basis over the 100 frame run, in order to obtain a more quantitative measure of correlation between electrodes. Figures 5-20 through 5-23 show the results of this integration for several different filter bandwidth runs. Each bar represents the SYNDET trace integration of one frame. The 65-85 Hertz runs clearly show an increase in level during mental tasking.

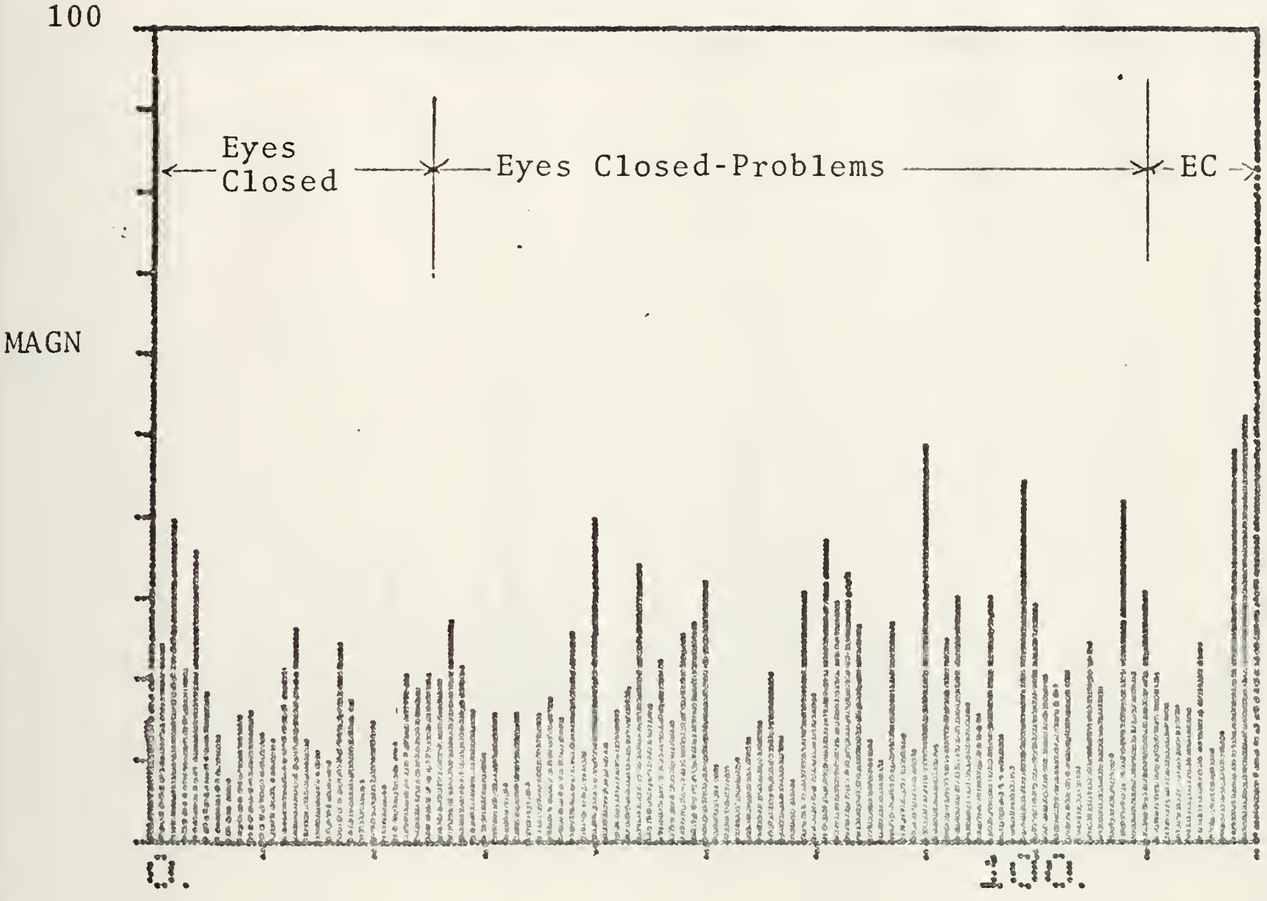


Figure 5-20. Frame-by-frame integration of SYNDET trace from electrodes one and two over a 100 frame run (5-25 Hz bandwidth).

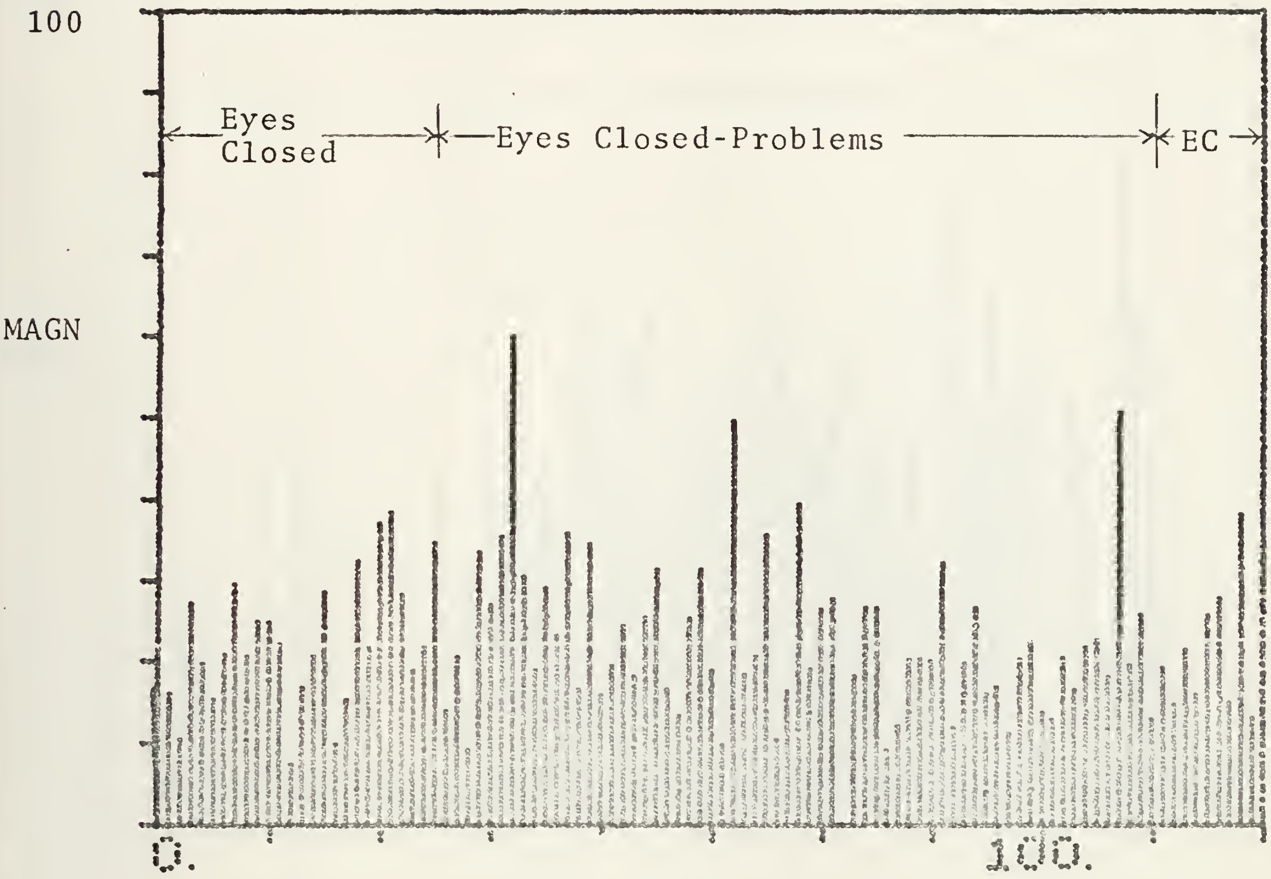


Figure 5-21. Frame-by-frame integration of SYNDET trace from electrodes one and two over a 100 frame run (30-45 Hz bandwidth).

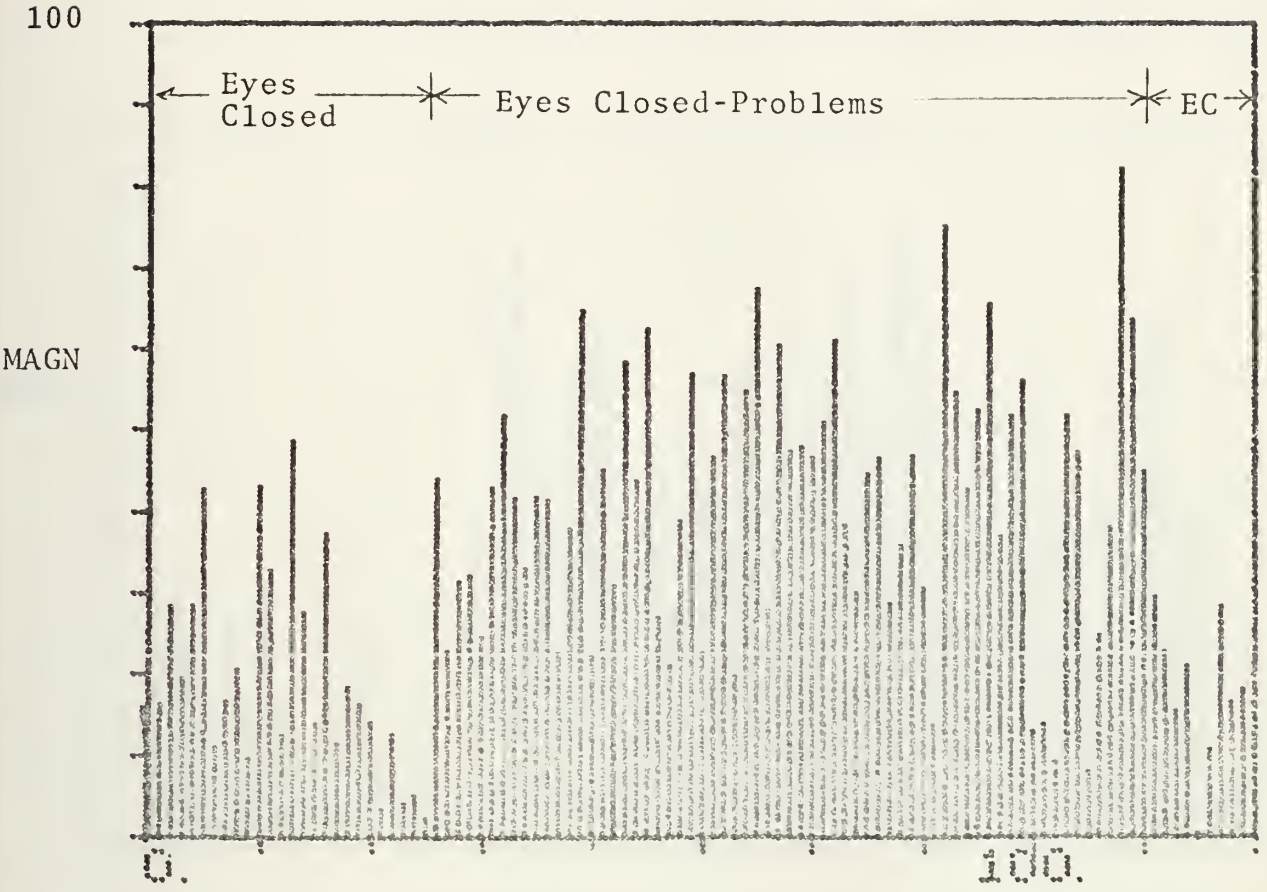


Figure 5-22. Frame-by-frame integration of SYNDET trace from electrodes one and two over a 100 frame run (65-85 Hz bandwidth). Note the increased level during eyes closed-problems.

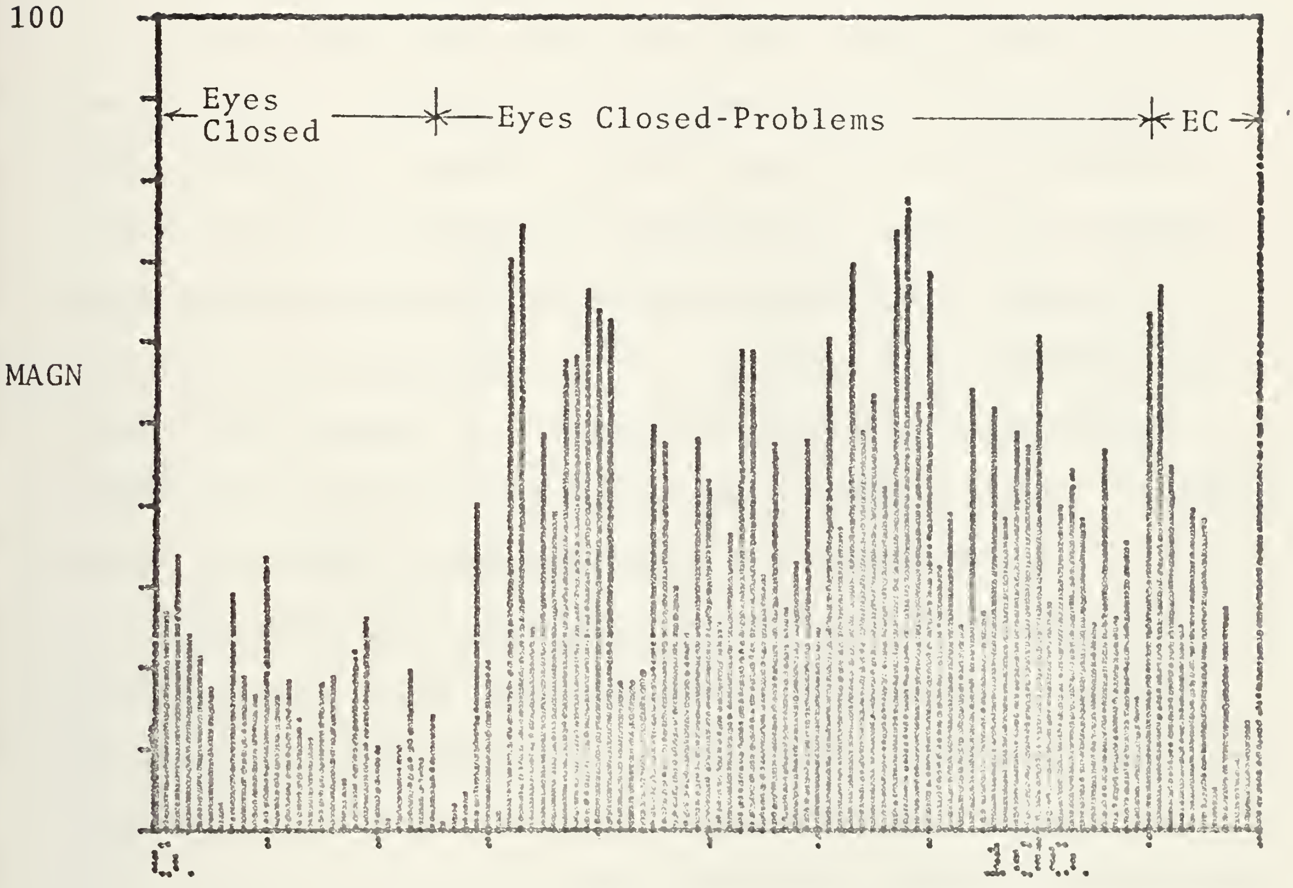


Figure 5-23. Frame-by-frame integration of SYNDET trace from electrodes one and two over a 100-frame run (65-85 Hz bandwidth). Note the increased level during eyes closed-problems.

VI. DISCUSSION

A. CORRELATION ESTABLISHED

It has been shown that due to the tegular nature of filtered EEG's a synchronous detection method of determining the correlation between cortical locations is a sensitive indicator of instantaneous correlation. Models of tegules were made and multiplied together in different phase and frequency configurations. The resultant model SYNDET patterns gave insight to the pattern obtained during actual SYNDET runs, and confirmed the clear SYNDET pattern obtained when correlation existed between two electrodes.

The amount of correlation between two electrodes has been observed to be both frequency and location sensitive. At frequencies below 50 Hz no significant change in the degree of correlation has been observed between closely spaced electrodes, at the particular locations chosen, when the subject is relaxed and then engaged in mental activity. Research conducted to date indicates that at the 65-85 Hertz range the amount of correlation depends on mental activity, with the greater correlation occurring when the subject is engaged in mental tasks. (Figs. 5-17, 5-18, 5-21, 5-22.) It is possible that at other electrode locations correlation may occur at different frequency bands.

B. OTHER FINDINGS

Close examination of the long 18-frame records of the SYNDET and EEG traces reveal several items of interest:

1. A curious phenomenon was observed on the 65-85 Hertz runs. There was a noticeable time lag in the subject's response from going from eyes closed-relaxed to eyes closed-problems and when going from eyes open-problems to eyes closed-relaxed. One would not expect to get a one to four second delay. To the subject, the mental change seems instantaneous.

2. Another curious phenomenon was the correlation patterns that seemed to appear when many frames were graphed on a long trace. On the SYNDET traces, correlation seemed to occur in groups of three or more peaks. The pattern is elusive and as yet not completely definable.

3. If, after looking at EEG traces, one had to estimate an average tegule length, one would guess it at about 0.1 second. This is, of course, the period of alpha, which then leads one to speculate that alpha must be some sort of strobing signal in the brain.

C. WHY THE TOP AREA WAS CHOSEN

It has been determined from physiological studies in lower animals that *all* areas of the cerebral cortex not immediately associated with either sensory or motor functions play an important part in the ability to learn complicated information. Furthermore, memory seems to be distributed throughout the cortex and not isolated specific areas.

Knowledge of these facts made it difficult to choose a site at which to start our investigation. The temporal-occipital-parietal (TOP) junction was chosen as the site of

initial investigation for our studies because it is known that this particular area is especially important for many of the intellectual functions of the cortex [Ref. 6]. Electrical stimulation in this area causes highly complex thoughts. Destruction of this area in an adult is known to cause a great void in his intellect [Ref. 2]. Neurophysiological experiments in this area have also determined that this area is an important association area that receives auditory, visual, and tactile information.

The objectives of the thesis were accomplished using this area for electrode placement and having the subject engage in simple mental tasks which consisted of solving easy, rapid-fire math problems. This type of mental task is only one type of mental processing by the subject. There are indications that another type of mental task would involve a completely different mental process [Ref. 11]. Would this process occur at the same or at different frequencies? This will be the subject of further investigations.

D. A NEW APPROACH

It is felt that Dr. Marmont's team investigation is a new approach in that:

1. The research team is not limiting its area of investigation to frequencies less than 50 Hertz. Loewegia, Siminova, and Creutzfeldt in their investigation of EEG changes during performance of various tasks restricted their investigation to less than 50 Hz EEG components [Ref. 11]. Indeed it is at frequencies well above 50 Hertz that show the most promise

of giving us more insight into mental processes. As stated earlier, Professor Marmont's HISCAN program is revealing what appears to be preferred frequencies in the 60-250 Hz range. Some of these frequency bands are different when the subject is involved in mental tasks as opposed to when he is relaxed. Other bands are found to be the same during both states. In either case the prospect of investigating this phenomenon further is exciting, and should give valuable new insight into the mechanics of mental processes.

2. Using the PDP-11 computer is giving the team the capability of digital filtering, real-time analysis, and data storage. Being able to store the raw data from EEG's on disc and then reprocess it in any number of ways has been most helpful.

3. Rather than limiting itself to the traditional stimulus response approach, [Ref. 12], the team is concerning itself with the investigation of actual thought processes; what recognizable patterns exist, how they differ, and how they may be similar.

E. FEEDBACK POSSIBILITY

Once one has a signal that is different when the subject is relaxed and when he is engaged in mental tasks, one then has the means to feedback a signal to reinforce or maintain the mental thoughts. Such a feedback signal could be displayed to the subject as a light, as a change in background illumination, as a color, as an audio tone, or as a visual display in which the feedback signal varies some parameter of the display.

The team has a Heads Up Device (HUD) System, which is a display system used in aircraft. This device has excellent feedback display potential. Clearly, the possible feedback methods are numerous. The only constraint is that the signal must in some way help to maintain or reinforce the desired thought processes. It is felt this exciting prospect is close at hand.

BIBLIOGRAPHY

1. Dollar, S. E., Multidimensional Analysis of the Electroencephalogram Using Digital Signals Processing Techniques, Engineer's Thesis, Naval Postgraduate School, 1973.

2. Guyton, A. C., M.D., Textbook of Medical Physiology, Fourth Edition, Saunders, 1971.

3. Curtis, B. A., Jacobsen, S. and Marcus, E. M., An Introduction to the Neurosciences, Saunders, 1972.

4. McWey, R. E., Signal Processing and Characterization of the Evoked Cortical Response, MS Thesis, Naval Postgraduate School, 1974.

5. Huhta, J. C. and Webster, J. G., "60 Hz Interference in Electrocardiography," IEEE Transactions on Biomedical Engineering, Vol. BME-20, No. 2, March 1973.

6. Netter, F. H., The CIBA Collection of Medical Illustrations - Volume One, Nervous System, CIBA Publications, 1972.

7. Gray, H., Anatomy of the Human Body, Lea and Febiger, 1973.

8. Adey, W. R., "Spontaneous Electrical Brain Rhythms Accompanying Learned Responses," The Neurosciences: Second Study Program, Rockefeller University Press, N.Y., 1970.

9. Frost, J. D., "EEG-Intracellular Potential Relationships in Isolated Cerebral Cortex," Electroencephalography and Clinical Neurophysiology, 1968, 24:434-443, Elsievier Publishing Company, Amsterdam.

10. Walter, D. O., "The Indeterminacies of the Brain," Perspectives in Biology and Medicine, Vol. 11, No. 2, Winter, 1968.

11. Legewie, H., Simonova, O. and Creutzfeldt, O. D., "EEG Changes During Performance of Various Tasks Under Open- and Closed-Eyes Conditions," Electroencephalography and Clinical Neurophysiology, 1969, 27:470-479, Elsevier Publishing Company, Amsterdam.

12. Creutzfeldt, O. D. and Kuhnt, U., "The Visual Evoked Potential: Physiological, Developmental, and Clinical Aspects," Electroencephalography and Clinical Neurophysiology, Suppl. 26, 1967 Elsevier Publishing Company, Amsterdam.

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